From Risk to Reliability:
# RESILIENT INFRASTRUCTURE SERVICES TO FACE NATURE'S CHALLENGES

**EDITED BY**
Lisa Bagnoli and
Eduardo Cavallo

IDB

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# Preface

Latin America and the Caribbean is increasingly exposed to a wide range of natural hazards. Since 2000, the region recorded 1,632 natural disasters that caused more than 260,000 deaths, affected over 200 million people, and generated losses exceeding $398 billion. Beyond the human toll, these events leave lasting economic scars: in low- and middle-income countries, natural disasters cause a permanent loss in GDP between 2.1 and 3.7 percentage points, and without decisive action, damages could rise to as much as $100 billion annually across the region by 2050. These shocks—such as hurricanes, droughts, floods, wildfires, earthquakes, and landslides—together with gradual climatic changes such as rising temperatures and sea levels, threaten the continuity of essential infrastructure services and disproportionately harm the most vulnerable. As the region urbanizes and modernizes, embedding resilience in infrastructure is no longer optional; it is central to inclusive and sustainable development.

This publication, *From Risk to Reliability: Resilient Infrastructure Services to Face Nature’s Challenges*, is the result of a collaborative effort across the Infrastructure and Energy Sector of the Inter-American Development Bank, bringing together the expertise and insights of the divisions of Transport, Water and Sanitation, and Energy, as well as the Public-Private Partnership Unit. It reflects a shared commitment to advancing resilient infrastructure systems that withstand shocks, adapt to changing conditions, and keep delivering services when they are most needed.

This volume offers a comprehensive framework for action. It begins with a diagnosis of the risks and vulnerabilities that infrastructure systems face in the region, followed by a review of the policy and technical toolkit available to build resilience across planning, design, operation, and maintenance. It then explores the funding and financing mechanisms needed to close the resilience investment gap, recognizing the challenges of mobilizing resources for infrastructure that deliver long-term, often intangible benefits. Throughout, the analysis is grounded in evidence, enriched by regional case studies and global experience.

While the report highlights promising strategies and tools, it also acknowledges the limits of our current knowledge. There is still much we do not know about which policies and investments are most effective in building resilience. The lack of hard evidence on what works—and under what conditions—is a key barrier to scaling up resilient infrastructure. Addressing this gap requires a concerted research agenda that includes rigorous evaluations, standardized metrics, and stronger collaboration between governments, the private sector, academia, and development institutions.

The IDB is already acting at scale to support this agenda. The Disaster Risk Management Action Plan 2026-2030 positions resilience as a core institutional priority. It introduces the flagship initiative *Ready and Resilient in the Americas* and strengthens innovative platforms such as RiskHub and RiskMonitor to empower decision-makers with better data and tools. At the same time, financial instruments such as contingent credit lines, risk-transfer mechanisms, and protection facilities are being expanded to provide governments with the fiscal space needed when disasters strike.

Within the Infrastructure and Energy Sector, resilience is at the core of our operations. Recent approvals illustrate this direction: flood-resilient road corridors that safeguard connectivity in Central America; nature-based water security projects in the Caribbean and South America that restore ecosystems while protecting communities; and investments in climate-resilient energy grids across Small Island Developing States to ensure reliable power supply under extreme conditions. Each of these operations demonstrates that resilience is no longer an add-on but a defining feature of sustainable infrastructure investments.

The stakes could not be higher. If left unaddressed, climate and disaster risks could drain the equivalent of decades of development progress, with annual losses in the hundreds of billions of dollars. But the opportunity is even greater. As this report shows, shifting from risk to reliability is not only about avoiding damages—it is about unlocking trillions in potential economic, social, and environmental benefits. By embedding resilience in every investment, the region can safeguard lives and livelihoods, reduce costs, and foster inclusive and sustainable growth.

This publication is both a resource and a call to action—for policymakers, practitioners, and researchers—to work together in building infrastructure that meets the challenges of today and tomorrow. We hope this report will inspire new thinking, inform better decisions, and catalyze the partnerships needed to move from risk to reliability.

**Tomás Serebrisky**
Manager, Infrastructure and Energy Sector
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The report contains a number of extremely valuable boxes. Thanks are due to the following authors of these important contributions:

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CHAPTER 1

# Resilient Infrastructure in Latin America and the Caribbean: Diagnosing Risks, Advancing Solutions, and Mobilizing Investment

In October 2023, Hurricane Otis escalated from a tropical storm to a Category-5 hurricane in less than 12 hours, slamming into the Mexican port of Acapulco. Power lines collapsed, roads flooded with mud and debris, and hundreds of thousands of residents lost essential services for hours. That same year, a drought in Montevideo, Uruguay forced authorities to relax water quality standards, with direct impacts on public health and user satisfaction. In February 2024, fast-moving wildfires in Chile became the country's deadliest on record, killing more than 130 people and destroying thousands of homes. A few months later, record floods swept through Brazil's southern state of Rio Grande do Sul, leaving at least 183 persons dead, more than 580,000 displaced and over 3.15 million without access to drinking water.

Episodes of this kind are not statistical anomalies. Globally, meteorological disasters (storms or extreme temperatures), hydrological disasters (floods and landslides), and climatological disasters (wildfires and droughts) have all risen dramatically in recent decades; Latin America and the Caribbean is no exception (Cavallo, Hoffmann, and Dueñas, 2025). The region sustains 22 percent of the world's most severe floods (which is three times higher than the region's global population share) and faces distinct hazard patterns, from storms—particularly in the Caribbean and Central America—to droughts—especially in South America—and temperature anomalies across the region (Blackman et al., 2025). While the frequency of geophysical disasters (earthquakes and tsunamis) has not changed, they can also be very destructive.

Transport, energy, water, and sanitation networks are crucial for virtually all social and economic activities. They enable mobility and trade, power hospitals and schools, and safeguard public health. When even one of these systems is disrupted, losses propagate quickly. The poor quality of infrastructure in the region hinders well-being and productivity, and the disruptions caused by weather variations and natural disasters aggravate problems. If infrastructure systems are not designed to be resilient to weather and natural shocks, the risks of service interruption and cascading effects on the economy and society become even more pronounced.

The burden of these events falls hardest on vulnerable groups. Poor households are more exposed to natural disasters and suffer more from their impacts. In Latin America and the Caribbean, at least 78 million poor people live in areas highly exposed to climate-related shocks (Bagolle, Costella, and Goyeneche, 2023). And when disasters occur, poor households lose proportionately more assets than wealthy households due to their exposure and to fewer resources to prepare for and recover from the effects of climate shocks. Vulnerable populations may also reside in areas with lower quality infrastructure and less service redundancy, exacerbating service disruptions and their consequences on livelihoods and well-being.

Hazard exposure is only one of many pressures currently facing the region. The convergence of challenges includes low investment, persistent gaps in access, quality, and affordability of infrastructure services, and underinvestment in resilient infrastructure.[1] These challenges are compounded by high levels of urbanization—Latin America and the Caribbean is one of the most urbanized regions in the world—demographic shifts—including internal migrations and population aging—and the imperative to decarbonize economies in line with global climate commitments.[2]

These challenges strain infrastructure systems and highlight the need to invest better. Aging infrastructure like power plants or sanitation plants are scheduled for replacement; rapid urbanization requires new and expanded transport systems. These investment needs provide a chance to embed resilience—the ability to anticipate, absorb, and quickly recover from shocks, as well as to adapt and transform in the face of long-term changes (Grünwaldt, Glass, and McCarthy, 2021)—into every new project. Crucially, resilience is not indestructibility; it is an adaptative approach that weighs social costs and benefits under uncertainty to reduce risk, protect the continuity and quality of service, and speed recovery. Resilient

1 See Cavallo, Powell and Serebrisky (2020).
2 See Blackman et al. (2025).

infrastructure can prevent, absorb, adapt, and rapidly recover from shocks like natural disasters, weather variations, or other shocks (UNDRR, 2022). It keeps doing its essential job and provides quality services, even when things go wrong. And it does not just bounce back—it learns, adapts, and becomes better at handling future challenges. Resilient infrastructure yields large savings by avoiding costly rebuilding and service disruptions in the future. Since these savings are particularly pro-poor, planning and building resilient infrastructure is not only a technical or economic objective, but also necessary for equity and shared prosperity.

The present volume addresses the issue of resilience in the sectors of energy, transport, water, and sanitation with a comprehensive, evidence-based analysis, structured around three core themes: the diagnosis of risks and vulnerabilities associated with climate-related and other disruptions that are prevalent in the region; the policy and technical toolkit for resilience in infrastructure; and the funding and financing mechanisms required to close the resilience gap.

## Diagnosing the Impacts: Climate Variability, Disasters, and Infrastructure Vulnerability

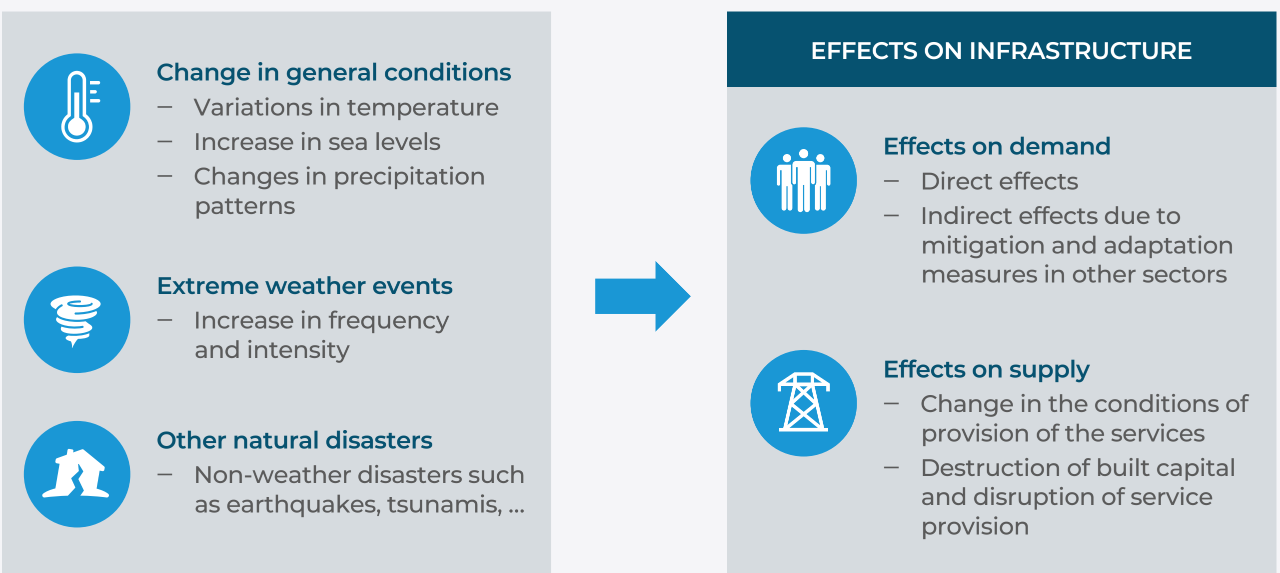
Chapter 2 presents an assessment of how weather variations and other natural disasters affect infrastructure systems and services in Latin America and the Caribbean. The region's infrastructure is exposed to a wide spectrum of hazards, ranging from droughts and floods to hurricanes and heatwaves, whose frequency and intensity are increasing under climate change. It is also subject to geophysical events, like earthquakes and tsunamis, due to its geographic location. But one thing is the "hazard"—who and what geographic areas are at risk—and another is the "incidence"—whether, when, and where the hazard materializes. Yet another consideration is the "impact"—who is affected, and how—when the disaster strikes. To become a disaster, a hazard must destroy human and physical capital. While many countries are exposed to climate-related and physical hazards, the incidence of disasters depends on the capacity of countries to confront them, making those impacts endogenous to economic development, including the quality and resilience of their infrastructure. In Latin America and the Caribbean, hazards often become disasters that disrupt both the demand for and provision of essential services, with cascading effects on households, firms, and macroeconomic performance.

Beyond sudden, disruptive disasters, infrastructure systems are also steadily affected by gradual changes in climatic conditions—including increasing temperatures and sea levels, and changes in precipitation patterns—that reshape both the demand and provision of infrastructure services.

Figure 1.1 summarizes these impacts and provides the conceptual framework followed throughout Chapter 2, which evaluates the impacts of slow changes in climatic conditions, extreme weather events, and other natural disasters. On the demand side, the effects are both direct—hotter days may drive up electricity use for cooling—and indirect—the push towards decarbonization in the transport sector and electric vehicles increases overall electricity needs. On the supply side, weather variations and disasters do more than destroy assets and disrupt services during extreme events; they also change the general conditions for service providers. Gradual climatic shifts, such as declining Andean glacier coverage, threaten the reliability or cost of operating water and energy systems, while extreme events like floods and landslides repeatedly damage transport and sanitation infrastructure.

**Figure 1.1**

Conceptual Framework: The Impacts of Weather Variations and Natural Disasters on Infrastructure




**Source:** Authors' elaboration.

The consequences of these disruptions are multidimensional. Direct physical damage to assets is only the initial impact; service interruptions propagate through supply chains, reduce productivity, and impose significant coping costs on public and private budgets. Vulnerabilities are not evenly distributed: geographic exposure, economic structure, and the quality and redundancy of infrastructure systems all shape the risk profile. Small island states and low-income countries are disproportionately affected, reflecting both higher exposure and lower adaptive capacity.

## Advancing the Policy and Technical Toolkit: From Diagnosis to Action

Building resilience requires more than recognizing risks; it demands a systematic approach to infrastructure planning, design, and operation. Chapter 3 synthesizes the state of the art in resilient infrastructure policy and practice, drawing on international experience and regional case studies.

A central insight is the need for robust risk assessment and prioritization frameworks. The spatial heterogeneity of climate-related and physical hazards in the region necessitates localized diagnostics and targeted interventions. Methodologies such as criticality and vulnerability assessments, blue spot analysis to prioritize investments, and decision-making under deep uncertainty are increasingly being mainstreamed into infrastructure planning, enabling authorities to allocate resources efficiently and adaptively.

The technical toolkit for resilience is evolving. Measures such as elevating assets away from flood zones, reinforcing structures, and updating design codes remain essential; but these must be complemented by nature-based solutions that leverage ecosystem services for risk reduction. The integration of green and grey infrastructure, for example, watershed reforestation, urban green spaces, and coastal ecosystem restoration, offers cost-effective and co-beneficial pathways to resilience.

Diversification, decentralization, and redundancy are recurring themes. Infrastructure networks that rely on a single source or centralized configuration are inherently vulnerable to shocks. Chapter 3 documents the value of diversified water sources (including desalination, reuse, and rainwater harvesting), distributed energy generation, and multimodal transport systems. Maintenance and asset management are also critical; underinvestment in operations and maintenance increases both lifecycle costs and vulnerability.

Demand-side adaptation is a promising yet underscaled policy lever. Early warning systems provide valuable information and reduce the exposure of the population to disasters. Information campaigns, behavioral interventions, and dynamic pricing are also important policy instruments that can nudge or incentivize consumers into efficient resource use, for instance, to conserve water during droughts.

Overall, the design of regulatory and institutional frameworks must facilitate innovation, flexibility, and cross-sectoral coordination, recognizing the interdependencies among infrastructure sectors and the need for coherent adaptation strategies.

## Mobilizing Funding and Financing: Closing the Resilience Investment Gap

Chapter 4 addresses the gap between the recognized need for resilient infrastructure and the resources mobilized to deliver it. Resilient infrastructure often entails higher upfront costs—due to enhanced design standards, redundancies, and nature-based solutions—while the benefits, such as avoided losses and service continuity, accrue over time and are often diffuse and difficult to monetize. This temporal mismatch complicates the political economy of investing, the mobilization of capital, and the design of equitable payment mechanisms.

The region's infrastructure investment gap is well documented: public investment in economic infrastructure has averaged less than 2 percent of GDP since 2015 (Brichetti et al., 2021), which is below the estimated need to achieve universal access to high quality, resilient services. While the public sector remains the principal investor, fiscal constraints and competing priorities limit its capacity to scale up investments. Private participation, though significant in some countries and sectors, is often concentrated and insufficiently aligned with resilience objectives. On average, private investment in infrastructure has been less than 1 percent of GDP since 2015. Multilateral development banks (MDBs) play a catalytic role, but their resources alone are not commensurate with the scale of the challenge.

A central theme of Chapter 4 is the need to clarify and innovate in both funding and financing. The distinction is not merely semantic: financing refers to the upfront capital—whether from public budgets, private investors, or blended sources, while funding is the ultimate source of repayment, whether through user fees (private funding), government transfers or earmarked taxes (public funding), or a combination of public and private sources of funding. For resilient infrastructure, the challenge is acute: many of the benefits are public goods or positive externalities not easily captured through direct user charges. This creates a need for public funding, risk-sharing mechanisms, and innovative financial instruments to bridge the gap between private incentives and social returns.

The chapter examines the evolving landscape of sustainable finance in Latin America and the Caribbean, including the rapid growth of green, social, and sustainability-linked bonds, as well as blended finance and climate adaptation funds. While these instruments are expanding the pool of available capital, the lack of standardized definitions, limited pipelines of bankable resilient projects, and persistent regulatory and institutional barriers dampen their impact. The analysis highlights the importance of robust enabling environments—regulatory frameworks, project preparation facilities, and risk mitigation instruments—to attract and sustain investment at scale.

## Toward an Actionable Agenda for Resilient Infrastructure

The three dimensions explored in this volume—diagnosis of risks, advancement of the policy and technical toolkit, and mobilization of funding and financing—are interdependent. Effective resilience requires an agenda that integrates risk assessment, adaptive planning, and innovative finance. It also demands institutional capacity, cross-sectoral coordination, and a commitment to evidence-based policymaking.

The stakes are high. Without decisive action, the region risks escalating losses from climate-related disruptions, widening gaps in access, quality, and affordability, and missed opportunities for sustainable growth. Conversely, investing in resilient infrastructure offers the prospect of reduced lifecycle costs, enhanced service continuity, and new economic opportunities—particularly for the most vulnerable populations.

This report offers policymakers, practitioners, and researchers a comprehensive, technically grounded, and actionable framework for advancing resilient infrastructure in Latin America and the Caribbean. It aims to inspire a new generation of infrastructure strategies—ones that are robust in the face of uncertainty, inclusive in their benefits, and aligned with the region's development goals. Yet, despite growing knowledge about how to build resilient infrastructure and its potential benefits, critical questions remain unanswered: What are its long-term impacts? What are the most cost-effective policies for advancing resilience? Which public policies best foster an enabling environment? And how can resilient infrastructure be financed sustainably? This report also seeks to illuminate these knowledge gaps and lay the groundwork for the research needed to close them.

CHAPTER 2

# In the Path of the Storm: How Weather and Natural Disasters Threaten Infrastructure

Weather variations, extreme weather events, and other natural disasters pose a challenge to infrastructure systems across Latin America and the Caribbean. Higher temperatures boost the demand for water and air-conditioning, rising sea levels encroach on coastal roads and ports, and more frequent and severe storms damage infrastructure assets and interrupt the provision of infrastructure services. These phenomena disrupt both the supply and demand for essential infrastructure services.

The repercussions go beyond the destructive impact on physical assets; weather events and natural disasters disrupt the provision of services. Individuals, households, firms, and countries all pay the costs of these disruptions with important social and economic consequences that hinder poverty reduction and sustainable growth.

Recent examples show how changes in climatic conditions and natural disasters disrupt essential infrastructure services for the population. In 2023, Montevideo, Uruguay was affected by its most severe drought in 74 years. By July, water reserves were at only 2 percent of capacity, forcing authorities to use higher salinity water to secure the water supply. The results were greater user dissatisfaction, damaged appliances, and hypertension among pregnant women and other susceptible users (Balza et al., 2025). During the same year, Hurricane Otis struck Acapulco, Mexico. The Category 5 hurricane intensified from a tropical storm in less than 12 hours, causing extensive destruction and interruptions to water, electricity, and internet services for more than a week (Balza et al., 2025). Gradual changes in climatic conditions also take a toll on services. For example, the reduced availability of water resources lowers the capacity of hydropower plants to generate electricity, thereby increasing the potential for blackouts, as happened in 2024 in Ecuador (IMF, 2024).

Given the calamitous impacts of climate change and disasters, there is an urgent need to increase the resilience of infrastructure services to changes in demand as well as to the threat of service disruption. Designing effective policies requires a thorough diagnostic of the effects of climate change and natural disasters on infrastructure as well as a better understanding of the determinants of vulnerability. The goal of this chapter is to provide such a diagnostic.

Throughout the chapter, the focus is on the effect of three main types of events: changes in general climatic conditions—such as increases in temperature or changes in precipitation patterns—, the greater frequency and intensity of extreme weather events, and the incidence of other natural disasters.[3] The chapter assesses how these events affect the demand for infrastructure services via, for example, the demand for water, electricity, and transportation services, as well as through the indirect effects on energy demand that come from adaptation and mitigation measures in other sectors. The chapter also provides evidence on how weather variations and natural disasters disrupt the provision of infrastructure services via changes in operational costs and conditions under which service providers must operate, or via the destruction of assets and service disruptions (see Figure 1.1). The chapter then lays out the effects of these general shifts and disruptions on households, firms, and the economy, and presents the main determinants of the vulnerability of infrastructure systems—geographic, economic, and systems characteristics—to weather and natural disasters.

## Demand-Side Pressure on Infrastructure Services

Climate change is a present and real danger that impacts the demand for infrastructure services (Balza et al., 2025). Understanding these effects allows policymakers to plan the delivery of infrastructure services to meet the challenges and increase resiliency to climate change, not only through supply-side policies, but also through demand-side policies.

3 The following natural hazard is noted for reference, although outside the scope of this report. Solar storms caused by intense bursts of solar radiation can disrupt power grids by inducing geomagnetic currents that overload transformers and damage infrastructure. While geomagnetic storms of varying intensity occur regularly, only four major events since 1932 have significantly affected the global power grid. Utilities must prepare for these rare but potentially severe events by investing in grid hardening, real-time monitoring systems, and contingency protocols to mitigate widespread outages.

One example is water demand. Despite the abundance of freshwater resources in Latin America and the Caribbean, a large portion of the population faces high water stress. Latin America and the Caribbean is the most water-rich region in the world, with approximately one-third of the world's freshwater resources and only 8.5 percent of the population. Still, millions of people face water stress. Water endowment is skewed within and between years but also concentrated in the less populated areas; 35 percent of the population lives in areas of medium-high to extremely-high water stress (Carrera et al., 2018).[4]

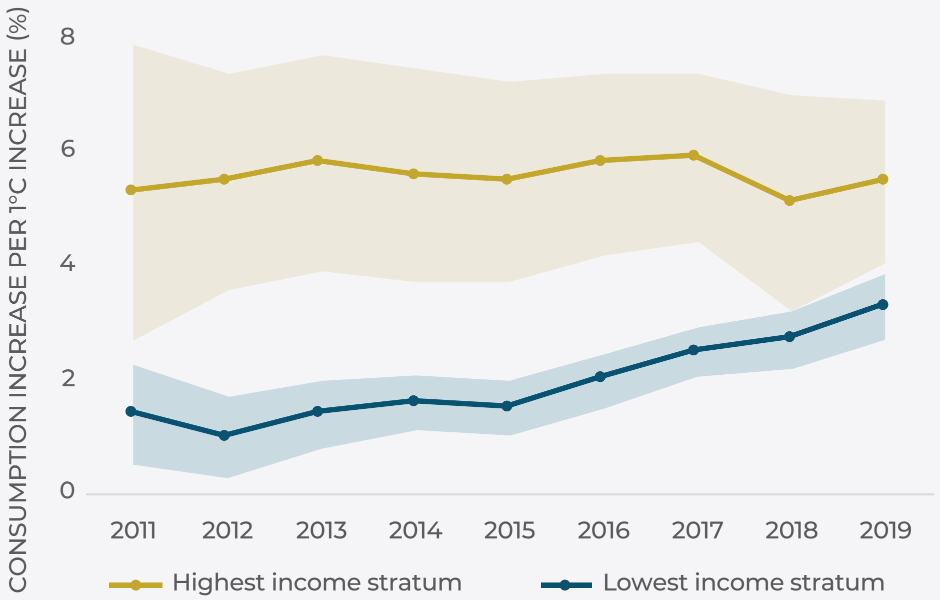
Climate change increases pressure on water resources through increased demand and higher competition across sectors. Guaranteeing water access to the population and securing water supply are already challenges, and the situation will only worsen given the pressure on water resources from population growth and the climate change effects on demand. Higher temperatures translate into higher demand for residential needs. However, other sectors also see an increase in water demand due to climate change; irrigation needs for agriculture, water needs for electricity generation, mining, or other water-intensive industries, further increase competition among users (Balza et al., 2025; IPCC, 2023; Ferrazzo Naspolini, Libra, and Pérez-Urdiales, 2024).

Energy demand is also rising due to climate change. Temperature anomalies put greater pressure on residential cooling and heating, which increases energy demand. An increase of 1°C above current global temperatures would increase worldwide cooling demand by about 25 percent (IEA, 2018). A recent study in Colombia reveals that higher temperatures cause an increase in electricity consumption, but with important differences across household types: the effects are larger for higher-income households who can afford to buy and use air conditioning (McRae, 2023). Each additional degree Celsius raises electricity consumption by 6 percent for wealthier households and by 2 percent for lower-income households, with the gap between income strata shrinking over time (see Figure 2.1).

4 Water stress varies widely across countries, with figures as high as 79 percent and 82 percent in Mexico and Chile. Moreover, the 35 percent average figure for Latin America and the Caribbean rises to 65 percent of the population when accounting for the lack of quality or access due to low institutional capacity (Libra et al., 2022).

**Figure 2.1.**

Effect of Heat on Electricity Consumption across Different Income Strata




**Source:** Authors' elaboration based on McRae (2023).

**Note:** The analysis only considers hot regions in Colombia. The shaded areas show 95 percent confidence intervals.

These impacts of climate change on energy demand also imply a direct impact on energy poverty. Global evidence shows that temperature increases, temperature deviations, and precipitation can increase poverty levels among the most vulnerable segments of the population (Wu, Hu, and Zhang, 2025; Feeny, Trinh, and Zhu, 2021). In milder climates, an increase in temperature can reduce the reliance of households on heating and alleviate poverty energy, as has been shown in the case of Australia (Churchill, Smyth, and Trinh, 2022).

Policies to address climate change in other economic sectors can also affect the demand for electricity. For example, in the case of carbon emission mitigation policies in transport, reaching the goal of having 10 percent of vehicles in Latin America be electric by 2030 requires a 1.2 percent increase in power demand (López et al., 2022). The same applies to climate adaptation policies. For instance, boosting resilience to droughts increases the reliance on groundwater extraction and desalination plants, both of which use energy-intensive processes (IEA, 2021a; Balza et al., 2025).

Climate change is also expected to affect transport demand by altering when and where people travel. As temperatures rise, tourism patterns may shift in response to changes in travelers' preferred destinations and the timing of their trips. Similarly, changes in temperature and precipitation patterns can affect agricultural production, where goods are shipped, and in turn freight transport. The frequency and intensity of extreme weather events may also affect the demand for transport if some routes become prone to repeated damage or destruction (Koetse and Rietveld, 2009).

## A Two-Pronged Hit to the Provision of Infrastructure Services

Climate change also affects the supply of infrastructure services in at least two ways. First, weather changes and the availability of natural resources influence the general conditions under which operators and utilities can provide services, reducing the availability and quality of resources or increasing operational costs. Second, extreme weather events can destroy or damage the physical assets that are necessary to provide services, leading to service interruptions (Balza et al., 2025). This is compounded by the impacts of non-climate-related natural disasters that also destroy or damage infrastructure assets and disrupt the provision of services (Cavallo and Noy, 2011).

### Shifts in General Climatic Conditions

Slow changes in the general climatic conditions driven by climate change pose significant challenges to providing water services to the population. For instance, lower precipitation can lead to drought emergencies, which can put significant pressure on the population (see Box 2.1 for the cases of Uruguay, Mexico, and Colombia).

## BOX 2.1. Tailored Responses to a Common Challenge: Drought in Latin America and the Caribbean

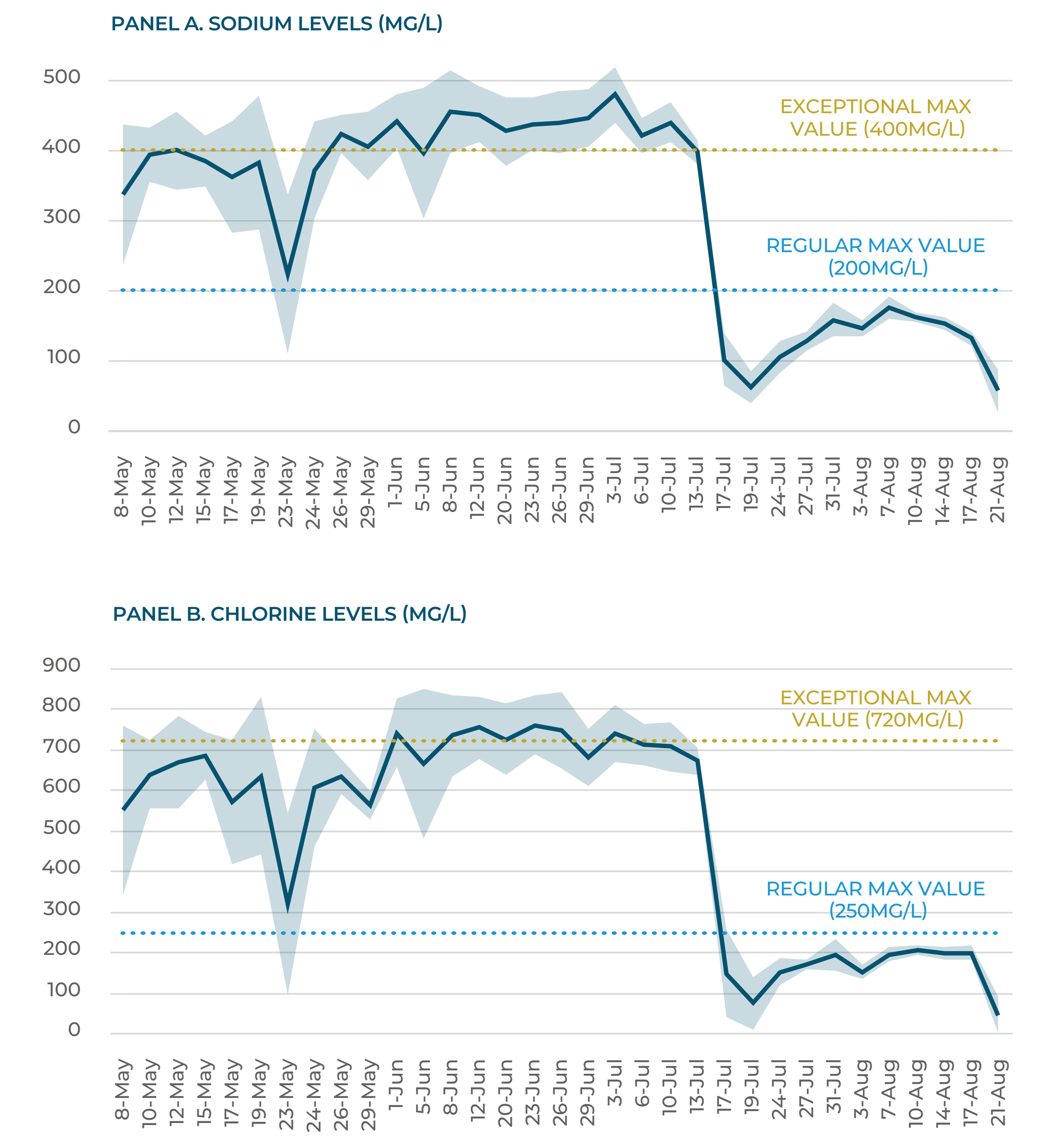
In recent years, several cities in Latin America and the Caribbean have faced drought emergencies, but their populations were impacted differently due to varying policy responses.

### Uruguay

The drought in Uruguay during 2023 was one of the most severe in recent history, primarily caused by the La Niña phenomenon, which led to significantly reduced rainfall. Compounding the weather issues were distribution system losses of 40-50 percent. The result was severe water shortages in the metropolitan area of Montevideo. The main water sources, such as the Paso Severino reservoir, were critically low, prompting the government to declare a state of emergency.

To cope with the crisis, higher salinity water from the Río de la Plata was pumped in during early 2023. As the drought worsened in April and May of 2023, the Ministry of Public Health approved exceptional maximum values for sodium and chloride in potable water production (see Figure B2.1.1 for the historical series of recorded sodium and chloride values). As a result of this relaxation in water quality standards, 37 percent of households switched from drinking tap water to bottled water, and the perception of water quality deteriorated (El Observador, 2024).

**Figure B2.1.1.**
Mean Sodium and Chlorine Levels in 2023

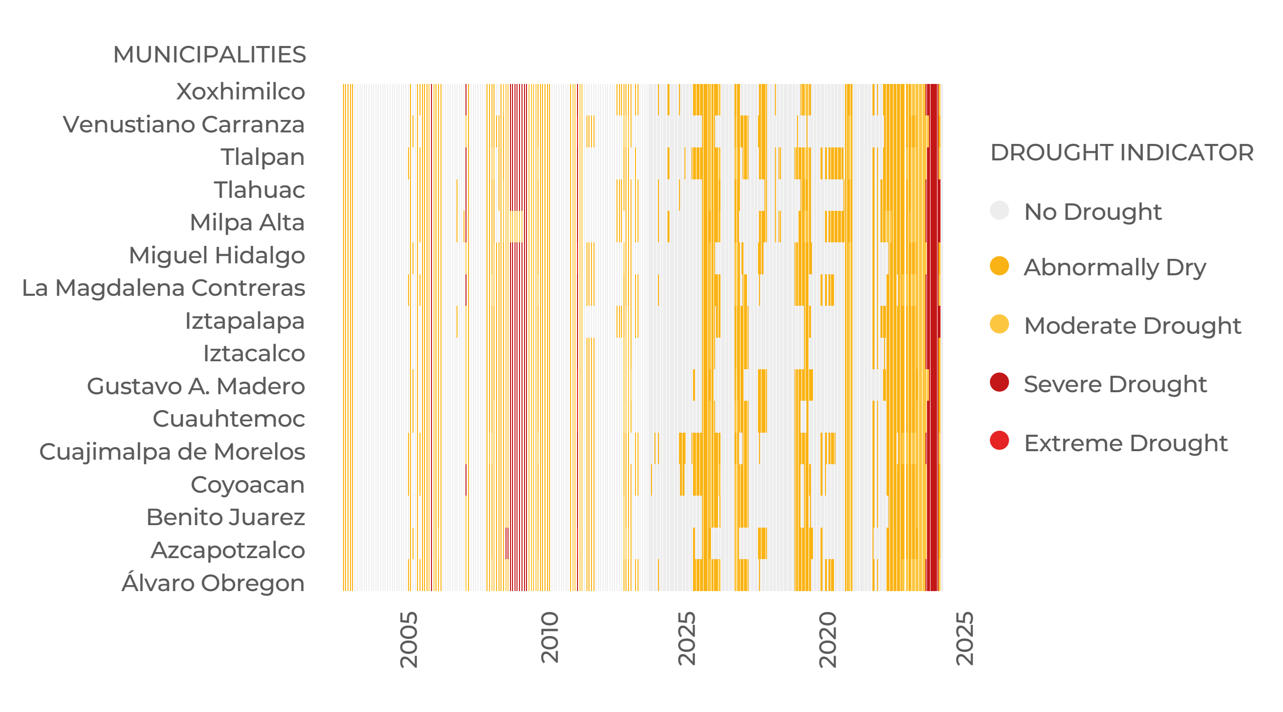



**Source:** Authors' elaboration based on data from Intendencia de Montevideo, Montevidata (2023).

## Mexico

Since the summer of 2023, Mexico has endured one of the most severe droughts in over a decade, which intensified throughout 2024. By early 2024, all boroughs in Mexico City were under severe drought alert (see Figure B2.1.2).

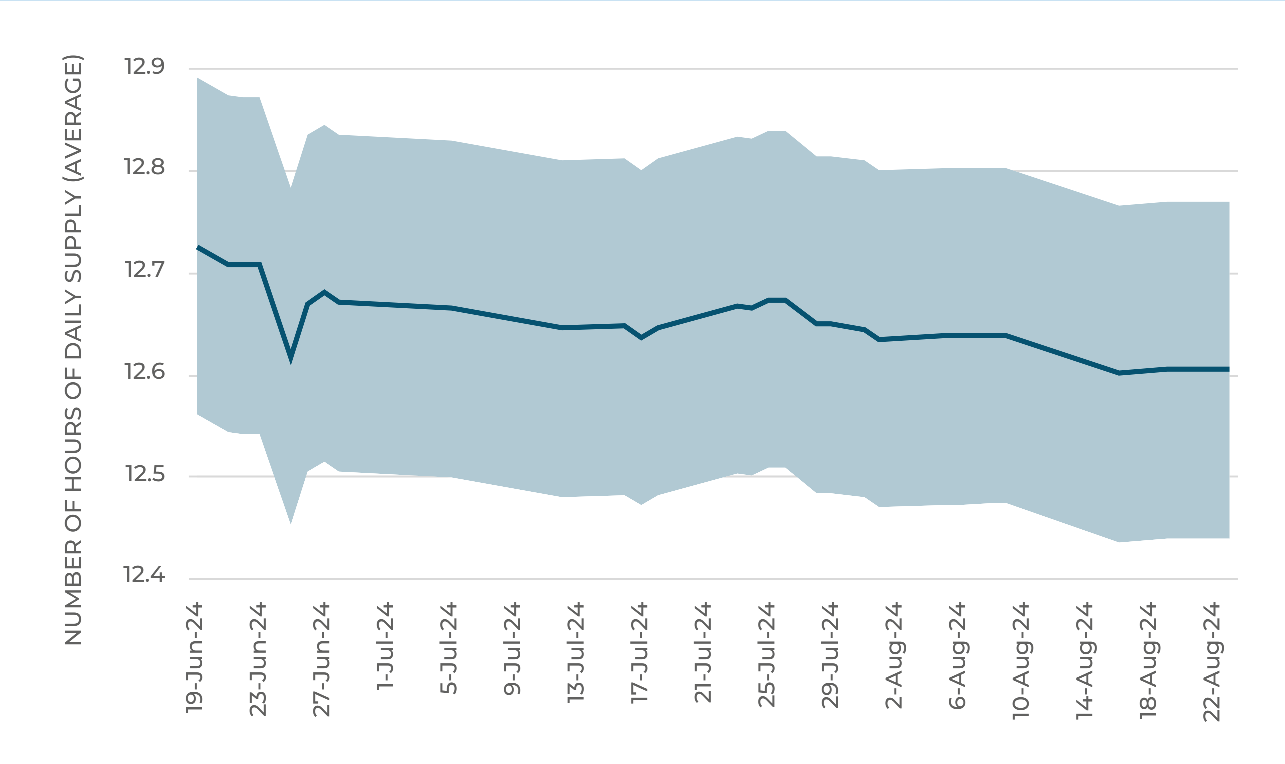
**Figure B2.1.2.**
Drought Monitor in CDMX, 2003-2024




**Source:** Couleau and Pérez-Urdiales (forthcoming-a).

June 26th was popularly dubbed "Day Zero," the anticipated day when Mexico City would deplete its water reserves. Although this scenario was averted, the city experienced intermittent water supply cuts (see Figure B2.1.3). The crisis was eventually mitigated through a combination of rainfall, increased reliance on aquifers, and political interventions during the concurrent election period.

**Figure B2.1.3.**
Evolution in Continuity of Water Service




**Source:** Couleau and Pérez-Urdiales (forthcoming-a).

## Colombia

Bogotá also experienced a significant drought in 2024, necessitating scheduled water supply cuts starting on April 11th. These measures included periods of stricter and more lenient rationing, which have persisted into 2025.

Moreover, higher temperatures chip away at glacier coverage, which acts as natural water reservoirs. Melting glaciers decrease water availability and disrupt seasonal flows, causing both droughts and floods at different times of the year. The Andean glaciers in Venezuela, Colombia, Ecuador, Peru, and Bolivia have lost between 20 percent and 50 percent of their area since the middle of the 20th century (Magrin, 2015). The quality of water is also affected by the runoff of glaciers as turbidity increases. Other events, such as wildfires or soil erosion, swell the sediment load in rivers, while higher water temperatures increase the severity, frequency, and localization of harmful algal blooms, which affect the taste and odor of water (IPCC, 2023). All these events pose threats to human health if they remain unaddressed. Consequently, operators are faced with the need for additional water treatment or higher pressure on extractive groundwater, increasing operational costs for water provision as well as for wastewater systems (Balza et al., 2025). A recent survey showed that around two-thirds of water utilities in the region reported greater expenditure on chemicals for water treatment due to climate change (Solis and Serebrisky, 2023).

Changes in climatic conditions coupled with the availability of natural resources also affect energy generation and transmission (Nascimento et al., 2017). Variations in wind patterns, solar exposure, cloudiness, and air density affect energy generation from wind farms and solar power plants. Heat also affects solar power generation as it reduces the efficiency of photovoltaic cells and damages cells and other materials (IEA, 2022; Balza et al., 2025). High temperatures and heat waves also hinder the transfer capability of transmission lines, which in turn exacerbates energy losses and the risk of line sagging. Changes in precipitation and more frequent or intense droughts constrain the availability of runoff water, the main input to produce energy in hydropower plants (Talbot-Wright, Hallack, and Vogt-Schilb, 2023). This is especially critical for Latin America and the Caribbean, as hydropower generation accounts for more than half of the electricity mix—far more than in other regions (Balza et al., 2025). In Suriname, changes in rainfall patterns are expected to reduce power generation at the Afobaka power plant by 5-9 percent (depending on the climate scenario) and by 10-14 percent by 2100 (San Salvador Del Valle et al., 2022; Balza et al., 2025). Changes in electricity hydropower generation can also have indirect impacts on the population and on the energy transition depending on the type of technology used to replace the loss in renewable and non-polluting hydropower generation. Box 2.2 on droughts in Chile illustrates the indirect impacts of climate change on pollution and the use of fossil fuel through the channel of lower available natural and renewable hydrological resources. Overall, the vulnerability of different electricity generation sources highlights the value of diversification in the network. Relying on various sources increases the resilience of the overall generation to various shocks.

## BOX 2.2. Climatic Challenges to Electricity Decarbonization: Evidence from Chile

Climate variations increasingly threaten electricity security by impacting generation capacity, operational efficiency, and the resilience of transmission and distribution networks. The rising frequency and intensity of extreme weather events pose particular challenges for the decarbonization of the energy system, as renewable energy sources—such as hydropower, solar, and wind—are highly sensitive to climate variability. Among them, hydropower, which accounts for more than 15 percent of global electricity generation, is particularly vulnerable to the increasing frequency and severity of droughts, affecting both seasonal and year-to-year availability and generation capacity.

In a recent study, Bagnoli et al. (forthcoming) examine how electricity systems adapt to drought shocks, using Chile as a case study. The country's distinctive geography, characterized by parallel river basins flowing from the Andes to the Pacific, generates substantial subnational variation in drought exposure. Coupled with high-quality plant-level data spanning two decades, this setting enables the authors to examine how different generation technologies respond to drought conditions and assess the resilience of the electricity sector to climate stress.

Chile's electricity matrix underwent a significant transformation between 2003 and 2022. At the beginning of this period, generation was evenly split between hydropower and thermal sources. However, by 2022, the electricity matrix had evolved significantly: hydropower accounted for just 24 percent of total generation, while thermal comprised 47 percent, and variable renewable sources—solar and wind—rose to 17 percent and 11 percent, respectively. This transition occurred against the backdrop of a severe drought affecting the country's central regions, where most of the country's hydroelectric capacity is located.

Leveraging detailed plant-level data, Bagnoli et al. (forthcoming) examine this period to assess how drought conditions reshape electricity generation patterns:

- At the plant level, drought episodes led to a 17 percent reduction in hydropower generation, highlighting the vulnerability of this crucial low-carbon technology to climate extremes.
- Large thermal plants compensated for reduced hydropower output, with affected plants increasing their generation by about 25 percent during drought periods. This response was driven primarily by established thermal plants with available capacity rather than new investments.

These findings highlight important considerations for electricity system planning. While backup generation capacity is crucial for system reliability during weather-induced disruptions to renewable generation, the choice of backup sources and their geographical distribution must align with broader environmental goals. The research also suggests that market integration only partially mitigates weather shocks, as thermal plants respond to both local and system-wide drought conditions.

Chile's experience offers valuable policy lessons for managing weather-related risks in electricity systems. First, diversifying generation sources across different technologies and geographical areas enhances system resilience and helps reduce system-wide vulnerability to specific weather events. Second, the choice and location of backup generation capacity must balance both reliability needs and environmental impacts. Finally, strengthening grid interconnections and market integration can help mitigate the impacts of local weather shocks, although their ability to fully absorb extreme climate events remains limited.

As climate change increases the frequency and severity of extreme weather events, electricity systems must be designed to maintain reliability while minimizing environmental impacts. Chile's experience underscores the importance of system flexibility, resource diversity, and grid integration in achieving these objectives.

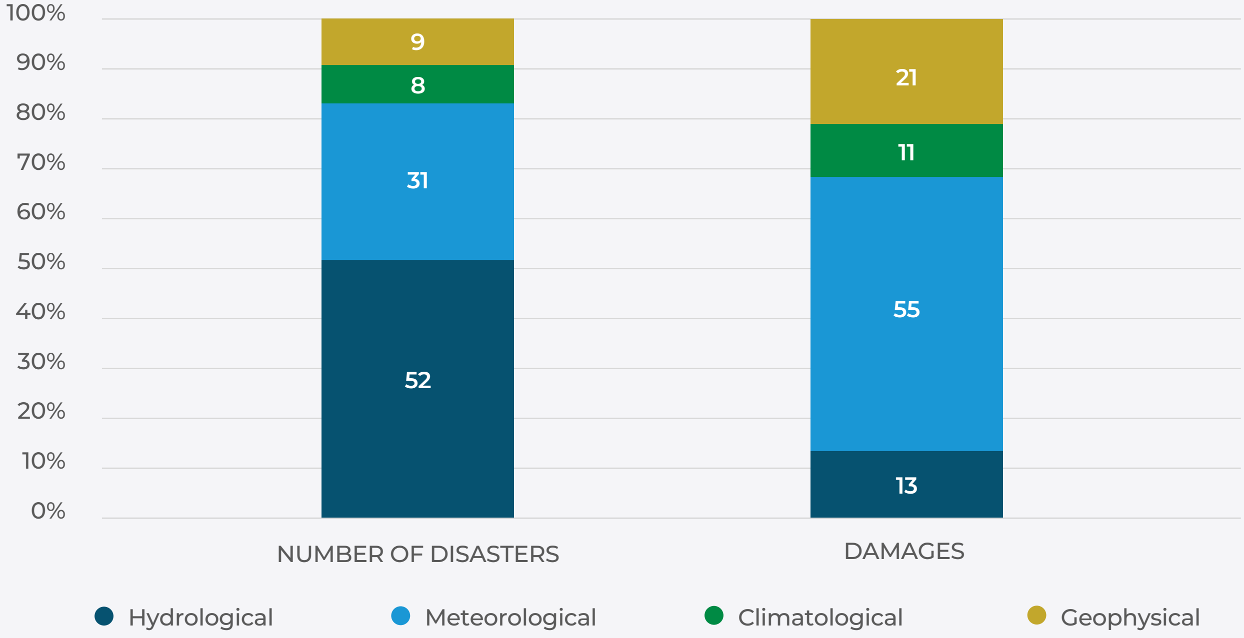
In transport, climate change can significantly affect the condition of roads, railroads, seaports, inland waterways, and public transport systems. More frequent and intense droughts and severe rainfall pose significant threats to the road infrastructure (Calatayud et al., 2023). Increased rainfall also exacerbates congestion, affects road safety, and leads to productivity losses (Koetse and Rietveld, 2009; Gordillo et al., 2015). Changing weather patterns are increasingly disrupting air and maritime transport. In aviation, more frequent storms, turbulence, and shifting wind patterns are affecting flight safety, scheduling, and the reliability of emergency services. Similarly, maritime transport faces rising sea levels, stronger storms, and altered ocean currents, threatening port infrastructure, vessel safety, and the stability of global trade. The main maritime ports in the region and airports in the Caribbean are vulnerable to rising sea levels (Camacho, 2024). Moreover, longer periods of low water levels can significantly increase the costs of inland waterway transport (Koetse and Rietveld, 2009). Droughts also affect maritime transport. For example, the Panama Canal handles about 3 percent of global maritime trade and relies heavily on fresh water, which makes it more vulnerable to climate change. Intense droughts since 2019 have limited crossings for large vessels, which affects world trade and notably increases prices for commodities while incurring revenue losses for the Panamanian Government (Calatayud et al., 2023).

## Destruction of Assets and Service Disruption

Beyond gradual changes in operational conditions, the supply of infrastructure services is also vulnerable to extreme weather events and natural disasters. The collapses, damage, and destruction of physical assets not only represent costs due to the destruction of capital, but they also importantly disrupt the provision of services to individuals, households, and firms, which in turn can trigger negative domino effects in other sectors (Kadri, Birregah, and Châtelet, 2014).

Natural disasters encompass various types of events. Hydrologic events, such as floods, have represented the largest number of disasters in Latin America and the Caribbean since 2000 (see Figure 2.2). They account for 52 percent of disasters and about 13 percent of total recorded damage. Meteorological disasters include storms and extreme temperatures. These account for 31 percent of events and 55 percent of damage. Climatological disasters include drought and wildfires. They account for fewer events and damages, 8 percent and 11 percent respectively, but can have important consequences by disrupting services such as electricity and clean water. Finally, geophysical events such as earthquakes or volcanic activity represented 9 percent of events in the region in the past two and a half decades, but up to 21 percent of total asset destruction.

**Figure 2.2.**
Type of Natural Disasters and Associated Damages (2000-2025)

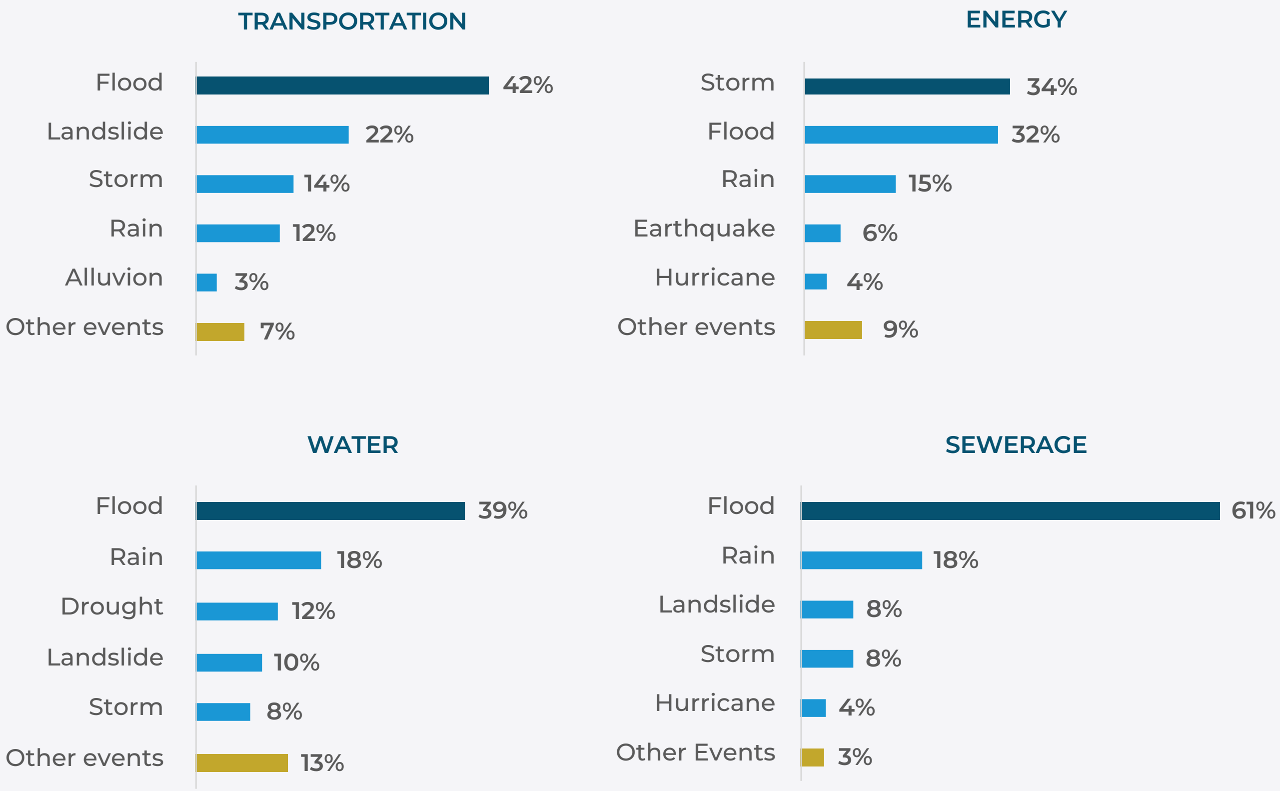



**Source:** Authors' elaboration based on data from EM-DAT: The international disaster database.

**Note:** The total number of natural disasters that occurred in Latin America and the Caribbean between January 2000 and May 2025 is equal to 1,617. Biological disasters were excluded in these computations (they account for 79 disasters and no economic damage). Damages are the value of economic losses directly or indirectly caused by the disaster, adjusted for inflation.

Floods are particularly problematic for infrastructure services. They represent the type of event most frequently encountered in transport (42 percent of all damaging events), water (39 percent) and sewerage (61 percent), and are a close second to storms in the energy sector (32 percent and 34 percent, respectively). The second most frequent type of damaging event is landslides for transport, and rain for water and sewerage.

**Figure 2.3.**
Infrastructure Damage by Service and Type of Event



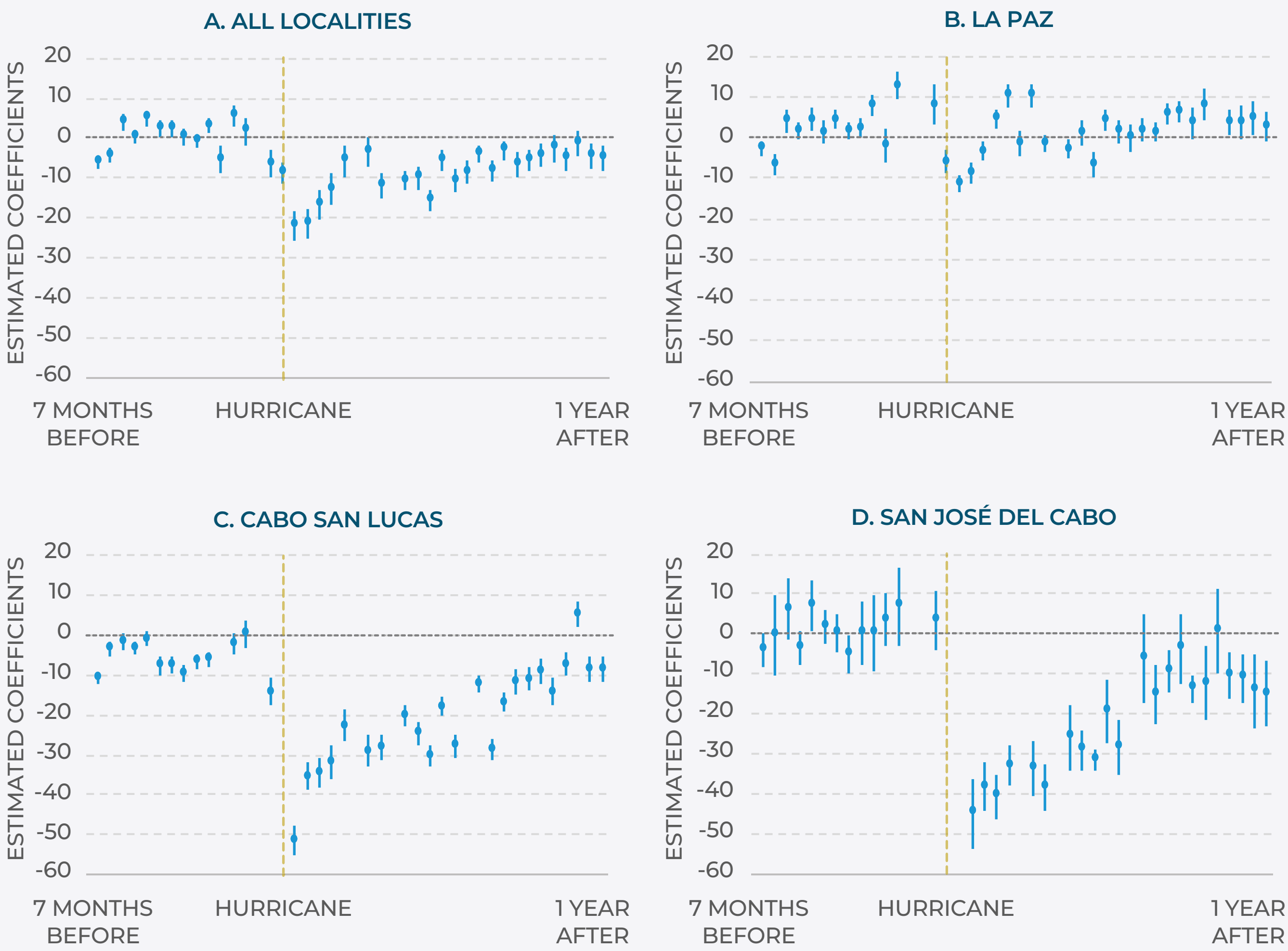

**Source:** Author's elaboration based on data from DesInventar (1970-2023).

**Note:** Share of events with damaging effects to infrastructure systems by sector.

Storms are considered one of the main causes of wide-range electrical disturbances worldwide (Panteli and Mancarella, 2015; Kenward and Raja, 2014). Indeed, these power interruptions tend to be of longer duration because of the high damage to transmission and distribution infrastructure. For instance, tropical cyclones and storms can severely damage distribution lines, poles, and transformers (IEA, 2022). In 2014, Hurricane Odile struck the state of Baja California Sur, Mexico. The intense winds destroyed power lines and compromised the supply of electricity to large urban centers, affecting 50 percent to 100 percent of users depending on the municipality. Bagnoli et al. (2025) used nighttime light data to assess the recovery patterns after the hurricane. On average, nighttime light dropped to 78 percent of its pre-hurricane level, with some localities reaching as low as 49 percent of pre-hurricane luminosity (see Figure 2.4). While it took two months to fully restore electricity service to the population, luminosity levels did not recover their pre-hurricane levels for a year after the disaster, indicating longer-term economic impacts, especially in a high tourism region such as Baja California Sur.

**Figure 2.4.**

Recovery Patterns after Hurricane Odile in Baja California Sur, Mexico, 2014




**Source:** Authors' elaboration based on Bagnoli et al. (2025).

Landslides also pose a threat to electrical infrastructure such as transmission lines (Balza et al., 2025). And infrastructure failures can also create or increase natural risks. For instance, during heatwaves and droughts, sparks in transmission or distribution lines close to vegetation caused by overheating can trigger wildfires, which in turn pose a severe threat to infrastructure assets and populations more generally (Hallegatte et al., 2019).

While water systems are vulnerable to extreme weather events, they are also key to reducing natural hazard risks related to floods and droughts (Hallegatte et al., 2019). For instance, dams are needed to manage downstream floods but can have catastrophic consequences if they collapse because of increased river flows (Hallegatte et al., 2019). Water and wastewater treatment plants are typically located in the lowest part of the network and are thus particularly vulnerable to floods. Box 2.3 illustrates the importance of flood impacts on water and sanitation infrastructure in Colombia.

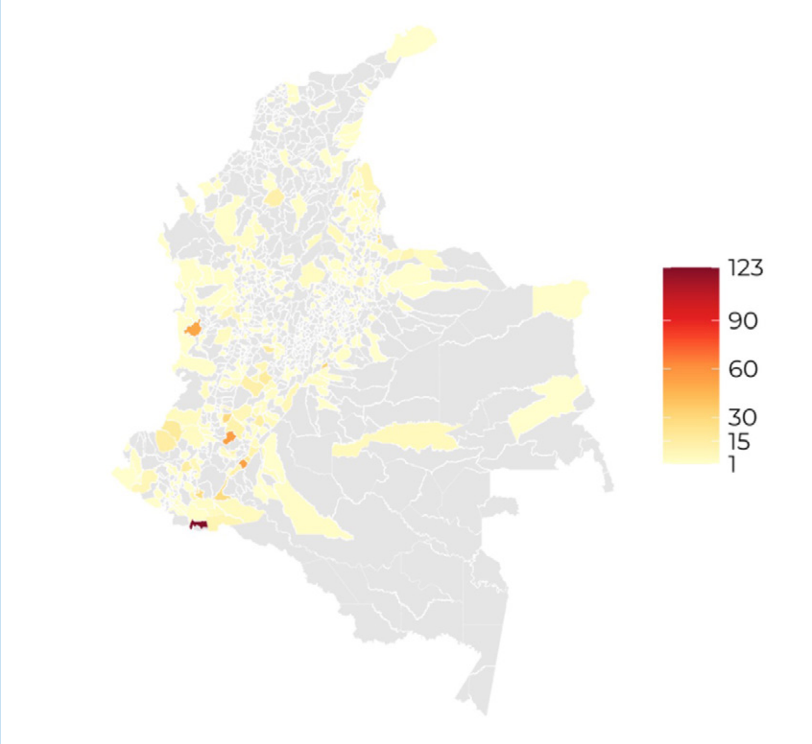
## BOX 2.3. The Impact of Floods on Water and Sanitation Infrastructure: The Case of Colombia

Water and sanitation infrastructure faces significant risks due to extreme weather events. Between 1998 and 2022, some 1,514 cases of water and sanitation infrastructure damage were reported due to floods in Colombia (see Figure B2.3.1). These events affected 335 municipalities that host 46 percent of the national population (Couleau and Pérez-Urdiales, forthcoming-b). The infrastructure damage occurs most often during La Niña phenomena (Vega, Barco, and Hidalgo, 2024). However, geographic characteristics play an important role as well; the most affected municipalities are usually located at higher altitudes (Cullen, Al Suhili, and Aristizabal, 2022) making them more vulnerable to infrastructure damage.

Floods can damage the water supply system through various channels. The most common damage is when systems exceed their capacity and overflow or sediment accumulates in pipes, resulting in service interruption, low pressure, and more difficult treatment processes due to higher turbidity or new pollutants. In extreme cases, the entire system—including the water treatment plant—is flooded, requiring a complete water supply shutdown. Floods can also damage sewer pipes due to excessive pressure, or inundate properties with sewage water due to inadequate drainage. Exposure to long-term floods such as during La Niña has been associated with a higher risk of diarrhea among children under five years old in low and middle-income countries. This risk is even higher when the floods are preceded by drought (Wang et al., 2023), which is common in a tropical climate like Colombia's.

Targeted interventions, early warning systems, and more resilient infrastructure can help mitigate the impact of floods. These mitigation strategies have an even greater effect on rural households where the connection to water and sanitation infrastructure is low. For instance, in the Valle de Aburrá (Antioquia, Colombia), the Administrative Department for Disaster Risk Management (DAGRD) implements early warning systems to mitigate the damage when the municipality's rivers overflow, especially during the rainy season. These systems, which include level sensors in rivers, sirens, community chat groups, and direct communication with authorities, aim to alert the population about potential floods and flash floods. This system allows for effective preventive evacuations. When a water-level sensor shifts from orange (indicating a minor flood) to red, the central platform monitoring river flows (SIATA) contacts community members for real-time observations before deciding whether to activate the sirens to warn residents (Área Metropolitana Valle de Aburrá, 2021). In addition, DAGRD carries out preventive interventions in high-risk areas to reduce flooding hazards; it cleans rivers of illegal landfills and conducts public education campaigns to prevent the accumulation of solid waste in waterways (Alcaldía de Medellín, 2022).

**Figure B2.3.1.**
Instances of Water and Sanitation Infrastructure Damage Due to Floods in Colombia, 1998-2022



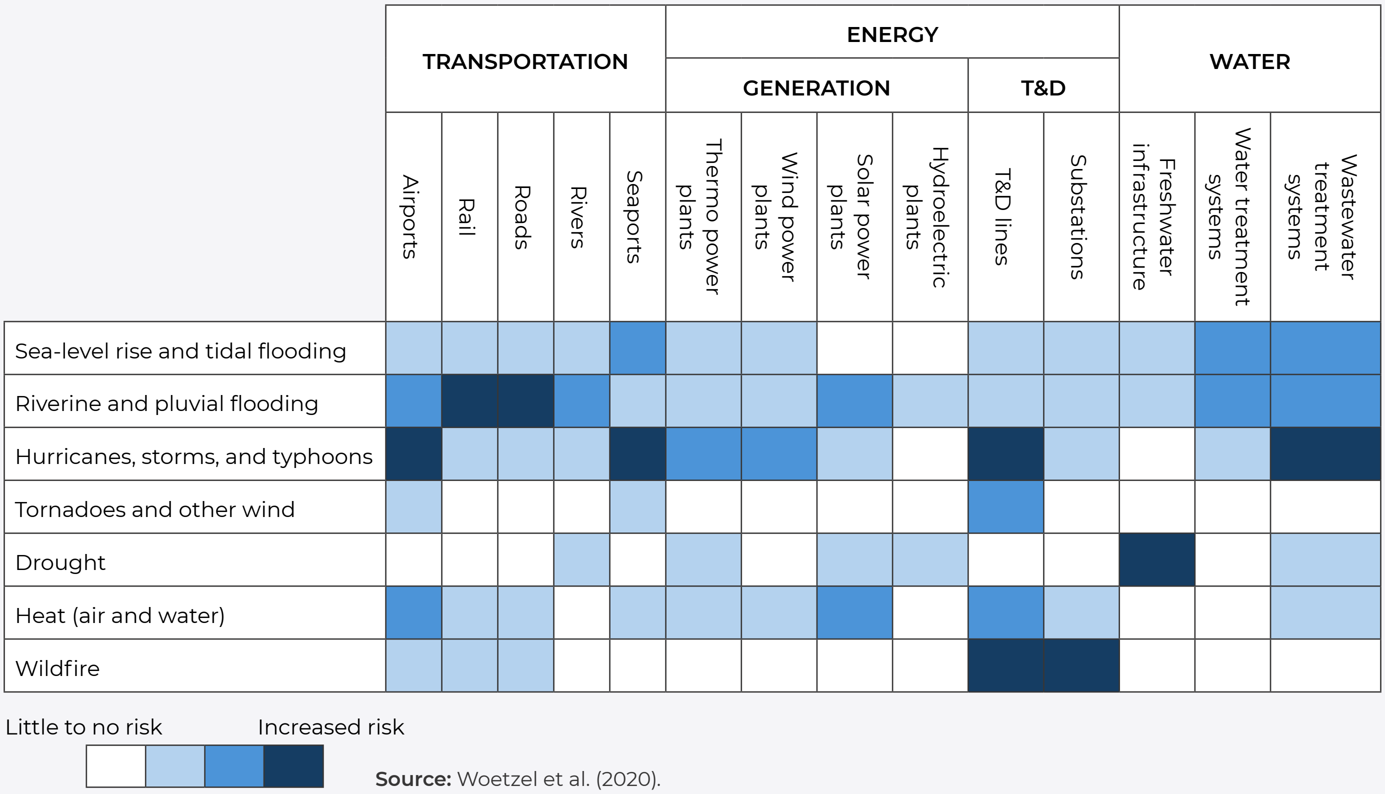

**Source:** Couleau and Pérez-Urdiales (forthcoming-b).

Natural disasters can also disrupt, damage, or destroy transport infrastructure, which can lead to significant social and economic losses caused by the service interruptions and potential isolation. The transport sector alone bears 25 percent of the losses associated with natural disasters (CAF, 2018). Landslides caused by heavy rainfalls, melting glaciers, or earthquakes pose a significant threat to road travel. These events damage assets and cause social and economic losses due to service interruptions, which can even exceed the value of damaged assets (Calatayud et al., 2023). For instance, in the Dominican Republic, hurricanes, river surges, earthquakes, and tsunamis inflict about $1 million in annual damage to the transportation network. However, losses for users are almost three times higher (Olaya González et al., 2022). Similar examples include the case of Hurricane Dorian in The Bahamas (2010) and Tropical Storm Eta and Hurricane Iota in Honduras (2020) (Balza et al., 2025). Businesses are particularly vulnerable to transport and supply chain disruptions; it is estimated that more than half (56 percent) of losses suffered by businesses in Latin America and the Caribbean after a disaster can be attributed to disruptions in the transport sector (Rozenberg et al., 2019).

In summary, the vulnerabilities of infrastructure assets to different types of events vary across sectors. Table 2.1 summarizes risk levels due to exposure to climate hazard by 2030 in each infrastructure subsector. It confirms that some climate hazards such as riverine and pluvial flooding pose some risk to all infrastructure subsectors, while hurricanes, storms, and typhoons pose an increased risk for at least one subsector of transportation, energy, and water. Moreover, each sector's assets are at risk to at least one other type of climate hazard. Floods are a threat to transport, wildfires for transmission and distribution of energy, and droughts for freshwater infrastructure.

**Table 2.1.**

Global Infrastructure Assets and Risk Level to Climate Hazard by 2030




**Source:** Woetzel et al. (2020).

**Notes:** Risk is defined as potential future losses (asset interruption, damage, or destruction) as a result of exposure to climate hazards. T&D: Transmission and distribution.

**Table 2.2.**
Impacts of Climate Change and Extreme Weather Events on Infrastructure Services

| | HIGHER TEMPERATURES AND DROUGHTS | EXTREME PRECIPITATION, FLOODS, EXTREME WINDS AND CYCLONES | CHANGES IN SEA LEVEL | EARTHQUAKES AND SEISMIC MOVEMENT |
|---|---|---|---|---|
| WATER AND SANITATION | Increase in water demand*<br>Water storage evaporation<br>Water table reduction due to increased pumping<br>Increase in pumping costs<br>Cracks and ruptures in distribution networks due to land subsidence<br>Increase in sediment load in rivers and lakes because of wildfires<br>Increase in the frequency, severity, and geographic distribution of harmful algal bloom in surface water sources<br>Increased odor in wastewater treatment facilities | Damage to physical infrastructure due to debris and inundation<br>Overflows in sewage and stormwater systems<br>Riverbank erosion<br>Stormwater system overflows<br>Increase in turbidity of surface water sources (increase in treatment costs or inability to treat) | Aquifer salinization due to sea level intrusion<br>Flooding of desalination plants<br>Flooding of coastal wastewater treatment plants | Damage to or rupture of pipelines and reservoirs, cutting off supply |
| TRANSPORT | Melting road surfaces and railway lines<br>Road damage from ground defrosting<br>Loss of navigation capacity due to low water levels<br>Road deterioration requiring more maintenance<br>Land subsidence due to aquifer overexploitation in drought | Demand* and supply changes due to aviation grounding<br>Roads and railways covered by water, mud, and debris<br>Road and railway losses due to soil erosion<br>Bridge collapse due to soil erosion and debris<br>Seaports' physical destruction<br>Temporary closure of ports and airports due to extreme winds<br>Flooding and damage to subway stations, bus stops, rolling stock, buses, etc. | Flooding of coastal roads<br>Flooding seaport infrastructure (sea routes closing)<br>Flooding of coastal airports<br>Bridge collapses due to rising water levels | Collapse of roads, rail lines, bridges, ports, and airports<br>Road and railways blocked by debris and ground deformation |

| | HIGHER TEMPERATURES AND DROUGHTS | EXTREME PRECIPITATION, FLOODS, EXTREME WINDS AND CYCLONES | CHANGES IN SEA LEVEL | EARTHQUAKES AND SEISMIC MOVEMENT |
|---|---|---|---|---|
| ENERGY | Increase in electricity demand led by more use of air conditioning*<br>Increase in electricity demand led by groundwater pumping and desalinization plants*<br>Reduced efficiency in solar panels<br>Reduction in hydro storage and electricity generation<br>Reduced power output due to warmer water in thermoelectric plants<br>Power outages due to unmanageable peak loads<br>Transmission line inefficiencies<br>Increased risk of wildfires from high temperatures and expanded transmission lines touching vegetation | Infrastructure flooding<br>Damage to power lines and hydro generation infrastructure by landslides<br>Power line collapses<br>Energy supply disruption<br>Damage to wind turbines and solar panels due to extreme wind speed<br>Damage to physical hydropower assets | Flooding of coastal power plants | Power lines collapse<br>Energy supply disruptions<br>Damage to generation plants, substations, transmission towers and lines, and distribution lines |

* Effects on the demand for infrastructure

**Source:** Authors' elaboration based on Balza et al. (2025).

## The Ripple Effects of Infrastructure Disruptions

Climate change and natural disasters increasingly disrupt infrastructure systems, leading to both physical damage and service interruptions. These disruptions not only affect the assets themselves but also significantly raise the cost and complexity of delivering infrastructure services. The consequences ripple through society, with profound social and economic implications for individuals, households, firms, and entire communities. These impacts manifest through multiple channels, including direct damage, coping costs, and indirect effects that accumulate over time.

For households, direct impacts include the short-term consequences of not having access to each infrastructure service and the benefits they provide. For instance, power outages can affect cooking and food conservation as well as heating and cooling, with its potential health consequences.

Indirect effects span from children's educational outcomes to limited access to jobs, markets, and services in general. Health impacts can stem from a lack of access to health care, lack of air-conditioning during heatwaves or heat during cold spells, contamination of water sources, air pollution due to congestion, or longer-term consequences of investments that were forgone because of the frequency and length of disruptions, such as in food refrigeration or air-conditioning. Finally, households may face coping costs that are required to increase their resilience to the adverse effects of climate change and natural disasters. These may include investments in generators, alternative water sources, or alternative transport modes (Hallegatte et al., 2019).

Disruptions in infrastructure services also affect firms' activities, reduce their productivity, force them to operate at lower capacity, reduce sales, and increase delays in supplies and deliveries. The main direct impact comes from lower utilization rates of power, water, and transport. Combined, these amount to $151 billion a year in losses worldwide (Hallegatte et al., 2019). Sales losses caused by power disruptions alone amount to $82 billion a year (Hallegatte et al., 2019). Indirect impacts include higher barriers to entry, lower investments, less competition and innovation, lower competitiveness in international markets, and biases toward labor-intensive production. Finally, the coping costs for firms also include larger investments in generators or alternative water sources (Solís, 2025). These may reduce, for instance, direct impacts of blackouts, but have high operating costs and require an up-front purchase that can prohibit alternative and more productive investments. Other coping costs include those related to moving to more expensive areas in order to avoid certain vulnerabilities (Hallegatte et al., 2019).

The combined effects on households and firms translate into significant macroeconomic consequences. Rising temperatures, for instance, have been shown to reduce GDP growth, with the magnitude of the impact depending on a country's baseline climate (Cavallo, Hoffmann, and Dueñas, 2025). In Latin America and the Caribbean, where most countries already experience warm climates, further temperature increases are projected to reduce GDP per capita growth by up to 22 percent in countries such as El Salvador and The Bahamas by 2050. Even in countries such as Chile, where aggregate GDP might benefit from warming, sectoral losses in agriculture, water, and energy are expected.

Natural disasters further compound these risks. In Latin America and the Caribbean, the economic impact of storms remains significant regardless of their intensity, unlike in other regions where only the most severe events have lasting effects. This suggests that the region is particularly vulnerable to the increasing frequency and severity of climate-related disasters. As a result, Latin America and the Caribbean faces heightened macroeconomic risks, with long-term implications for development and poverty reduction (Cavallo, Hoffmann, and Dueñas, 2025).

## Main Determinants of Vulnerability

The main determinants of vulnerability to climate change and natural disasters can be classified in three categories: (i) geographic characteristics, (ii) economic characteristics, (iii) characteristics of the system.[5]

### Geographic Characteristics

Not all countries or regions face the same threats because they do not all face the same exposure. Caribbean countries, and particularly those in the Small Island Developing States (SIDS), are particularly vulnerable to the effects of climate change. Located in the hurricane corridor, these countries are highly exposed to cyclones, tropical storms, and extreme winds, earthquakes, and tsunamis. Moreover, given their relatively small sizes, a large portion of the population and infrastructure is concentrated in high-risk coastal zones (Calatayud et al., 2023). For example, in The Bahamas, 25 percent of the population and 32 percent of the land are located less than 0.5 meters above sea level, making them particularly vulnerable to rising sea levels and to the destructive effects of extreme weather events that originate in the ocean (Strauss and Kulp, 2018). Indeed, the predicted rise in sea levels and the associated increased frequency of storm surges and flooding is considered to be one of the most worrying effects of climate change, particularly for coastal areas (Koetse and Rietveld, 2009). Additionally, Caribbean SIDS countries rely heavily on tourism, which represents between 11 percent and 79 percent of their GDP (Monioudi et al., 2018), thereby magnifying the impact of extreme weather events on their economies and labor markets (Calatayud et al., 2023).

Central America and the west coast of South America are situated within the "Ring of Fire", characterized by active volcanoes and frequent earthquakes, making it particularly vulnerable to these types of events.

5 Governance and institutional characteristics are also important determinants of the vulnerability and ability to recover from disasters. Relevant aspects include regulatory capacity, intersectoral coordination, and the overarching governance frameworks. These dimensions will be developed in greater detail in Chapter 3.

Indeed, 65 percent of the world's earthquakes with a magnitude of 8 or more since 2000 have occurred in South America (OCHA, 2023). In particular, Chile, Ecuador, and Guatemala have the highest seismic risk. However, other countries are also vulnerable to such threats. For instance, the consequences of the 2010 earthquake in Haiti were exacerbated by its high vulnerability, leading to over 222,500 casualties and ranking it as one of the top 10 deadliest earthquakes in human history (OCHA, 2023).

Finally, countries in the equatorial zone are more vulnerable to floods and landslides, which, combined with their mountainous topography, cause severe damage to road infrastructure (Calatayud et al., 2023).

### Economic Characteristics

The vulnerability of countries, communities, and individuals to natural disasters depends on their exposure and on their resiliency or capacity to cope with the shocks.

Lower-income countries are more vulnerable. In Latin America and the Caribbean, lower-income countries tend to be located in areas more vulnerable to disasters and in hotter latitudes, which worsens the effects of increased temperatures. While lower-income countries account for 74 percent of the global population, they suffer 93 percent of disaster-related mortality (Cavallo and Noy, 2011). Moreover, global warming slowed down the income convergence between countries globally in recent decades, as richer countries in colder climates tend to benefit more from increased temperatures (Diffenbaugh and Burke, 2019). The economic conditions of a country also affect its capacity to recover from shocks. Limited resources constrain a country's financial ability to address emergencies after disasters. Moreover, when countries are more reliant on agriculture, they are more vulnerable to weather shocks. On the other hand, when countries—especially larger ones—have a more diversified economy, they are better able to absorb negative shocks across sectors and regions (Cavallo, Hoffmann, and Dueñas, 2025).

Within countries as well, lower-income individuals face the highest risk (Hallegatte and Rozenberg, 2017). Lower-income households may have to settle in riskier areas, not only because of lower prices, but because these areas may also offer other opportunities; for instance, they may offer cheaper transport or job opportunities by virtue of being located closer to water (Hallegatte et al., 2017). However, exposure is only one component of risk; vulnerability is the other and includes both physical vulnerabilities and the ability to cope with the event. Poorer households tend to lose more when hit by a disaster (Bagolle, Costella, and Goyeneche, 2023). For example, while Hurricane Mitch in Honduras destroyed 3 percent of the assets of the richest quintile, it destroyed 18 percent of the assets of the poorest quintile of the population (Morris et al., 2002). Poorer people have fewer resources to prepare and invest in resilient assets, or to recover from the effects of climate shocks (Bagolle, Costella, and Goyeneche, 2023). Households in informal settlements—a fifth of urban residents in Latin America and the Caribbean—are in particular typically situated in high-risk areas, lack formal basic infrastructure services, and live in dwellings that do not comply with planning and building regulations (Libertun de Duren and González Jaramillo, 2025). In rural and remote areas as well, lower-income communities tend to have lower coverage of infrastructure services and are thus more affected by disruptions in service provision (Calatayud et al., 2023). Box 2.4 illustrates the links between climate change and vulnerable populations in the case of the transport sector.

## BOX 2.4. Climate Change, Transport, and Vulnerable Populations

Extreme climate events have increased significantly in Latin America and the Caribbean in recent decades, particularly extreme rainfall and flooding. Between 1900 and 2021, the annual frequency of floods in the region grew more than that of other natural disasters such as storms, landslides, and extreme temperatures (Calatayud et al., 2023). As climate change intensifies, these events are expected to become more frequent and severe, further straining already inadequate transport infrastructure serving vulnerable populations and further restricting their access to services that enhance their quality of life (Hallegatte and Rozenberg, 2017).

Vulnerable communities are often the most affected by disruptions in transport services during extreme weather events. In rural areas, many rely on deteriorated or poorly connected roads to access essential services such as healthcare, education, and employment (Scholl et al., 2022). In urban areas, they are frequently concentrated in peripheral neighborhoods where public transport services tend to be of lower quality and road infrastructure is largely deficient (Cavallo, Powell, and Serebrisky, 2020). In urban environments—where 81 percent of the region's population resides—, extreme rainfall often leads to severe flooding due to large impervious surfaces, resulting in substantial economic and social costs.

Flooding damages infrastructure, disrupts public transport services, increases congestion, and limits pedestrian and cycling mobility (Pregnolato et al., 2017; He et al., 2021). For example, in 2013, Buenos Aires experienced one of its most intense storms in five decades, affecting 350,000 people and causing $300 million in direct damages due to flooding on public transport routes and disruptions to mass transport systems (World Bank, 2016). In Rio de Janeiro, heavy rains have slowed bus speeds by 1.7 percent to 8.9 percent, leading to delays with an estimated annual cost of $56 million in wages (Chaves Maia, 2022).

Addressing the needs of vulnerable populations in transport policy design is essential for building more resilient and inclusive mobility systems. A recent analysis with regional scholars identified inclusion and transition as top priorities in the transport and climate change agenda for Latin America and the Caribbean. Critical research questions focus on understanding how decarbonization and adaptation policies impact inequalities in the region and how vulnerable populations are affected by climate events that disrupt the transport sector (Beltrán, Rivas, and Calatayud, 2024). Since these populations bear the greatest burden of climate-related impacts, integrating their needs into climate resilience planning can significantly enhance transport system performance and generate widespread benefits (AbdelMagid et al., 2023).

### Characteristics of the System

Finally, vulnerability to climate change and natural disasters is dependent on the characteristics of the infrastructure systems. The quality of infrastructure and the incorporation of resilient aspects in its design and maintenance are crucial for its capacity to sustain severe shocks. For instance, older, degraded power systems are significantly more vulnerable to severe weather conditions (Panteli and Mancarella, 2015; Shafieezadeh et al., 2014). The extent to which adaptation measures are incorporated into the design of infrastructure has important implications for their ability to withstand extreme weather conditions (Calatayud et al., 2023).

Redundancy is a crucial component of infrastructure systems that increases resilience for the population. Redundancy in the system is key to restoring access to the infrastructure service as soon as possible after natural disasters. However, in many cases, resource constraints and institutional and planning deficiencies lead to low redundancies in the system. In the case of road networks, for instance, interruptions in some segments in low-redundancy areas can generate severe isolation and supply shortages for the most vulnerable communities (Calatayud et al., 2023).

## From High Risk to High Reward

This chapter provided a diagnosis of the risks and vulnerabilities that infrastructure systems face in Latin America and the Caribbean. Changes in weather conditions affect the demand for infrastructure services. Higher temperatures increase the demand for residential water and electricity for air-conditioning, among other things. It also increases competition for water uses from different sectors and affects both passenger and freight transport patterns. Finally, demand for electricity can also increase because of mitigation and adaptation measures in other sectors, such as the electrification of vehicles or increased reliance on groundwater extraction.

Changes in weather conditions also affect the general conditions under which infrastructure services are provided. Temperature increases and changes in precipitation patterns are some of the factors that strongly affect the operational costs for water utilities across the region, which needs to spend more on chemical treatments and groundwater extraction. Droughts also affect energy generation, especially since Latin America and the Caribbean relies heavily on hydropower generation. Other renewable energy technologies can also be affected by other shifts in climate, such as heat waves. Finally, increased sea levels are particularly threatening for coastal road infrastructure as well as for maritime ports and airports located close to the ocean.

Natural disasters can cause significant damage to infrastructure assets, causing even larger social and economic losses because of service interruptions. Floods are particularly damaging to all infrastructure sectors. While less frequent, hurricanes and intense storms can also cause severe asset damage, losses in connectivity, and longer recoveries. The social and economic losses due to service interruptions can even exceed the value of the damaged assets and have long-term consequences for populations.

Infrastructure disruptions affect households and firms through direct and indirect impacts, as well as high coping costs, and also affect economies more broadly. Households face direct impacts when essential services such as water, energy, or transportation are interrupted, and bear high costs of adaptation when they can afford them. These impacts, as well as indirect effects, can have long-term negative consequences on health, poverty, and human capital development. Similarly, firms endure lower productivity, higher costs, and lower competitiveness in international markets. On a broader scale, climate change also negatively affects GDP growth through both increased temperatures and the increased frequency of extreme weather events or other non-weather-related natural disasters.

Geographic characteristics are a critical determinant of vulnerability. Small Caribbean islands are extremely vulnerable to climate change; they are located on the hurricane corridor and face intense threats of extreme storms, but they are also at risk of rising sea levels, with most of their population and infrastructure located on coastal areas. For non-island countries as well, coastal areas are particularly vulnerable to climate change. The western coast of Central and South America is particularly vulnerable to earthquakes and volcanic eruptions. Finally, areas with intense rainfall and mountainous topography face a high risk of landslides capable of severely disrupting infrastructure services.

Economic characteristics are also a key driver of vulnerability, amplifying exposure and limiting resilience for lower-income countries and communities. Many lower-income nations are in hotter regions, prone to extreme weather. However, with limited resources to adapt and increase resilience to these events, they experience higher disaster mortality and have a lower capacity to recover.

Finally, the characteristics of infrastructure systems—particularly their quality, redundancy, and how resilience and adaptation are integrated into planning—also significantly influence their vulnerability to climate change and natural disasters. Older or degraded assets, such as outdated power grids or roads that are not well-maintained, face heightened risks, while robust design and adaptation measures can improve survival and post-disaster recovery. Yet, many systems have low redundancy due to resource constraints and weak planning, which increases isolation and supply shortages, particularly in vulnerable communities.

Looking ahead, while the impacts of climate change and natural disasters on infrastructure are significant, they also present an important opportunity to build more resilient and sustainable systems across Latin America and the Caribbean. Designing roads, bridges, and ports to climate-resilient standards, combining traditional infrastructure with nature-based solutions that buffer storms and floods, diversifying energy sources with solar and wind, and using digital monitoring to spot failures before they cascade are already being implemented in several parts of the region. These approaches can reduce recovery times, lower lifecycle costs, unlock new economic opportunities, and help prevent the types of service disruptions that often generate the highest social and economic losses. Harnessing these opportunities requires forward-looking planning, improved institutional capacity, and adequate funding and financing mechanisms that reward long-term risk reduction. The next chapter builds on this idea by exploring concrete policies to strengthen the resilience of infrastructure services in the energy, transport, and water and sanitation sectors.

CHAPTER 3

# Resiliency: The Watchword for Infrastructure Policy

Climate change, extreme weather events, and natural disasters increasingly disrupt the infrastructure services that societies depend on—particularly water and sanitation, energy, and transportation. These sectors are essential for meeting basic needs, enabling trade, driving innovation, and supporting economic growth. Reliable access to these services is a cornerstone of productivity, competitiveness, and quality of life (Hallegatte, Rentschler, and Rozenberg, 2019; Cavallo, Powell, and Serebrisky, 2020).

Governments in low- and middle-income countries invest between 3.4 and 5 percent of GDP—about $1 trillion annually—in infrastructure (Fay et al., 2019). In contrast, Latin America and the Caribbean has invested barely 1.8 percent on average in recent years, underscoring the region's chronic underinvestment (Brichetti et al., 2021). The consequences are evident: electricity grids remain unreliable, water and sanitation systems insufficient, and transport networks overstrained. Quality and coverage vary widely across and within countries in the region, leaving millions of people subject to daily disruptions. Weaknesses in infrastructure are further magnified by natural hazards. Urban flooding, for instance, disrupts transport and power networks while spreading waterborne diseases through inadequate drainage and sanitation systems (Hallegatte, Rentschler, and Rozenberg, 2019). More extreme shocks can practically paralyze entire systems, as seen with Hurricane Maria in Puerto Rico (2017), Hurricane Otis in Acapulco, Mexico (2023), and the severe drought that affected Montevideo, Uruguay (2023). These examples highlight how limited investments, compounded by insufficient maintenance, translate into poor resilience making adaptation in infrastructure a central policy priority for the region.

As detailed in Chapter 2, the consequences of these shocks go far beyond physical damage. Interruptions in water, electricity, and transport services can trigger cascading effects in the economy and society, which amplify vulnerabilities across households, firms, and public services. Designing effective infrastructure policies to be ready to withstand and adapt to climate-related disruptions and other shocks is, therefore, essential to protect lives, livelihoods, and the economy.

Effective adaptation policies must address both the supply and demand side of infrastructure services. On the demand side, there is no space for waste. Consumption and investment patterns must prioritize efficiency and conservation of scarce resources, and be supported by instruments such as pricing policies or awareness campaigns. Demand-side policies also protect users, for example through early warning systems that help reduce the impact of disasters on the population. On the supply side, providers must ensure that infrastructure systems are planned, built, and maintained to operate under stress scenarios ranging from shifts in weather patterns to increasingly frequent and severe events. Achieving this requires strong policy frameworks that include planning under uncertainty, resilient design standards, climate-informed building codes, risk-based regulation of utilities, and contractual mechanisms that safeguard maintenance and service continuity. Addressing both dimensions is key to building resilient infrastructure: systems capable of minimizing service disruptions while protecting society and economic activity from a variety of shocks.

Building resilience also requires a shift in focus from individual assets to the continuity of services at the network level. This means identifying the most critical nodes of the networks and measures that reduce vulnerabilities, including reinforcing key assets, diversifying supply, and introducing redundancies into the system. In that sense, planning becomes a critical part of embedding resilience into every infrastructure project, as it helps identify risks and vulnerabilities, and prioritize investments and measures that ensure the continuity of essential services under stress.

This chapter presents a roadmap for resilient infrastructure across water and sanitation, energy, and the transportation sectors. It begins by examining where and how infrastructure should be built to withstand climate risks and other shocks and highlights the role of adequate maintenance. It then discusses diversification, decentralization, and redundancy as key mechanisms for building resilient infrastructure systems, as well as the role of nature-based solutions. The chapter also explores strategies to adapt consumer behavior, including information campaigns, early warning systems, and pricing incentives to reduce vulnerability and improve efficiency. It concludes with a forward-looking set of policy priorities to guide governments and stakeholders in advancing resilient infrastructure across the region.

# Where and How to Build Infrastructure

## Location, Location, Location

Decisions about *where* to build infrastructure are a cornerstone of readiness and resilience. Location shapes the type and scale of risks that infrastructure assets will face: rising sea levels and storm surges threaten coastal zones, while droughts, extreme heat, and water scarcity increasingly stress inland areas across the region. Location-specific planning—grounded in risk data and tailored to local vulnerabilities—ensures that infrastructure investments are effective.

In many Latin American and Caribbean countries, however, the lack of granular data on hazard exposure often leads to poorly targeted investments. Weak information systems and poor planning can make infrastructure projects up to ten times more costly (Hallegatte, Rentschler, and Rozenberg, 2019). To address this shortcoming, countries can adopt planning tools that support flexible and long-term adaptation. One such tool is robust risk assessment, which helps identify priority locations where investments will deliver the highest resilience dividends. For example, the Danish Road Directorate's Blue Spot methodology pinpoints road segments most vulnerable to flooding and helps prioritize interventions amid high climate and economic uncertainty. This approach has already been adopted in the Dominican Republic to guide road infrastructure investment decisions (Olaya González et al., 2022) (see Box 3.1).

**BOX 3.1.** Resilience in Transport: Blue Spot Analysis Methodology in the Dominican Republic

The Blue Spot Analysis (BSA) methodology identifies flood-sensitive areas in road networks, where a "blue spot" is defined as a road segment with relatively high flood probability and significant consequences (Climate-ADAPT, 2022). Initially developed under the SWAMP (Storm Water Prevention) project and applied to the Danish

Road Network in 2010 (Grauert, Hansson, and Hellman, 2010), the BSA is useful both to (i) identify the zones most vulnerable to natural events and (ii) propose and prioritize the most effective interventions amid high climate and economic uncertainty, with the aim of strengthening system resilience against possible threats (Olaya González et al., 2022).

In the Dominican Republic, the Ministry of Public Works and Communications (MOPC) together with the IDB implemented the BSA to prioritize road infrastructure investments considering climate change effects and estimate damages and losses caused by hydrometeorological events (Olaya González et al., 2022). The analysis helps prioritize interventions on the national road network and estimate their associated costs (Table B3.1.1).

**Table B3.1.1.**
Methodology for Estimating Damages and Losses in Road Infrastructure

| STAGE | DETAILS |
|---|---|
| 1. IDENTIFICATION OF AFFECTED AREAS | Ministry technicians identify affected road infrastructure elements (bridges, road segments, local roads). |
| 2. CLASSIFICATION OF ROAD INFRASTRUCTURE | Classified by type (bridges, local roads, highways), network level (national, regional, local), and paved or unpaved condition. Information is obtained from technician input or existing georeferenced road inventory data. |
| 3. DEFINITION OF AVERAGE RECONSTRUCTION COST | Determined using BSA outputs and the infrastructure classification. |
| 4. DAMAGE ESTIMATE | Damages (the economic cost to the government of rehabilitating infrastructure) are estimated from repair costs. Specifically, they are calculated as the percentage of average reconstruction costs—derived from the vulnerability function, extent of damage, infrastructure classification, and event magnitude—multiplied by the length of the evaluated segment. |
| 5. LOSS ESTIMATE | Losses (economic cost to society of being unable to travel due to infrastructure damage) are calculated by estimating the total time required—or elapsed time—for traffic rehabilitation in hours, then multiplying by the daily socioeconomic cost. BSA provides socioeconomic cost for each road segment under two scenarios: (a) if an alternative route exists between points A and B, and (b) if this segment is the only route to reach the destination. |

**Source:** Authors' elaboration based on Olaya González et al. (2022) and Suardí, Lefevre, and Rodríguez Porcel (2024).

Port authorities use the World Association for Waterborne Transport Infrastructure (PIANC) guidelines to assess the exposure of ports to storm surge and coastal erosion. Based on these assessments, interventions then follow an "elevate, defend, retreat" strategy: raising facilities above projected flood levels, strengthening coastal defenses, or relocating assets from high-risk areas (Van Houtven et al., 2022). Similarly, airports are applying climate risk frameworks developed by the International Civil Aviation Organization (ICAO) to assess threats from sea-level rise and extreme weather. Adaptation measures in airports include elevating runways, relocating critical equipment, and improving drainage systems (ICAO, 2022).

In the energy sector, climate risks threaten both supply and demand, with important implications for electricity systems in Latin America and the Caribbean. Decisions about where to build energy infrastructure are critical for resilience. The location of generation plants, transmission lines, and distribution assets largely determines the type and scale of risks they will face. Droughts and changing rainfall patterns threaten hydropower in river basins (Bagnoli et al., forthcoming), heatwaves and cooling-water scarcity affect thermal plants (Byers et al., 2020), and coastal power plants and substations face storm surges and sea-level rise (IEA, 2021b). As such, resilient electricity planning must go beyond traditional reliability criteria by incorporating location-specific risk analysis, uncertainty, and adaptive responses into expansion and operation decisions (Sauma, Poveda Bonilla, and Gil Sevilla, 2025). This requires systematic use of climate and hazard data to guide the placement of new assets, stress testing existing infrastructure, and scenario-based planning that accounts for deep uncertainty. Electricity systems must be built around three key principles: (i) proactive preparation, which includes identifying threats and developing stress-tested scenarios tailored to local conditions; (ii) rapid response and recovery, which ensures contingency protocols for assets in high-risk zones; and (iii) adaptation and learning, which involves adjusting investment priorities as new climate data and local impacts emerge. Embedding these principles into planning processes, supported by regulatory mandates and risk-based investment appraisal, ensures that energy systems minimize location-driven vulnerabilities and strengthen system resilience. These examples underscore that location-based planning links risk assessments with investment strategies and operational decisions to strengthen resilience. Planning allows governments to target and prioritize investments by relocating them when necessary, upgrading existing assets, reinforcing them when possible, or building new assets capable of withstanding shocks.

## The Nuts and Bolts of Resilient Construction

Designing resilient infrastructure requires more than choosing the right location; it also demands a shift in how infrastructure is built. Materials, design standards, and construction codes shape infrastructure systems and prepare them to withstand weather-related threats (Alvear et al., 2023). A good design demands engineering practices that consider climate realities, regulatory frameworks that reflect evolving risks, and increasingly, nature-based solutions alongside traditional grey infrastructure, to harness the benefits that nature offers.[6]

At the core of resilient construction is the use of materials and engineering criteria that can accommodate higher temperature thresholds, stronger wind loads, and more intense rainfall. Roads and drainage systems, for instance, should be designed to accommodate heavier downpours than in the past; energy grids and transport corridors may need to be relocated or reinforced given changing climate patterns; and water and sanitation infrastructure must be prepared for more frequent and intense flooding and droughts.

Globally, construction codes increasingly reflect the imperative of resilience. For example, urban design standards are evolving to explicitly accommodate rising temperatures and shifting precipitation patterns. California's Assembly Bill 296 promotes reflective pavements to counter the urban heat island effect—the phenomenon whereby urban areas are typically warmer than nearby rural areas— and encourages active transport, such as walking and cycling. The European Union has implemented a comprehensive legislative framework to enhance the energy performance of buildings, including the revised Energy Performance of Buildings Directive (EU/2024/1275) and the revised Energy Efficiency Directive (EU/2023/1791) (see Box 3.2).

6 Nature-based Solutions (NBS) refers to the strategic restoration, protection, or management of ecosystems to achieve development outcomes to address societal challenges by reinforcing the services provided by nature (IDB, 2024).

## BOX 3.2. Energy Efficiency in the European Union

In recent years, the European Union has intensified efforts to reduce emissions and adapt to rising temperatures by improving the full life-cycle performance of buildings, particularly new constructions (European Commission, 2024).

This involves enhancing energy efficiency through solutions tailored to local climate conditions, future climate risks, and cost-effective approaches to ensure indoor comfort. The urgency of this transition is underscored by the fact that two-thirds of heating and cooling in the EU still rely on fossil fuels, making their phase-out critical.

To align with its climate targets, the EU mandates that all new buildings must be zero-emission by 2030; the existing building stock must reach this standard by 2050. This is particularly pressing given that approximately 75 percent of current buildings are energy inefficient. The path toward zero-emission buildings (ZEBs) will be steered by Minimum Energy Performance Standards (MEPS), a core policy tool of the recast Energy Performance of Buildings Directive (EPBD). MEPS require member states to establish national frameworks that prioritize improvements in the worst-performing buildings and progressively raise performance requirements over time.

These standards play a dual role: they are essential not only for reducing emissions but also for increasing resilience to climate extremes—particularly the growing frequency and intensity of heatwaves. MEPS mandate improvements such as insulation, ventilation, and energy-efficient cooling, which maintain safe and comfortable indoor environments while reducing health risks linked to poor air quality and overheating.

At the same time, passive design solutions—such as shading, reflective materials, and heat-resilient architecture—help limit the need for energy-intensive air conditioning, easing pressure on electricity grids during peak demand. Adopting smart technologies, including smart meters, building performance simulations, and demand-responsive energy systems, further enhances efficiency and performance. Complementary efforts, such as expanding rooftop solar energy, adopting extensive and intensive green roofing systems, installing heat pumps, and providing infrastructure for electric vehicle charging and bicycle parking, contribute to the broader transformation toward cleaner, more climate-resilient urban environments.

The most notable building codes for climate resilience in Latin America and the Caribbean are found in Chile, Costa Rica, and several Caribbean nations, particularly those in the Organization of Eastern Caribbean States (OECS). Chile leads in integrating climate risk into building codes, especially for earthquakes, strong winds, and energy efficiency. Costa Rica has advanced codes of sustainability, energy efficiency, and hazard mapping, supported by strong institutional frameworks (Abell et al., 2017). In the Caribbean, countries including Jamaica, Dominica, and St. Lucia have adopted or adapted international codes (e.g., ICC codes) and regional standards like CARICOM Regional Energy Efficiency Building Code (CREEBC) for energy efficiency (Benavidez, 2021). The OECS model building code is widely used and updated to reflect evolving climate risks.

Some countries are also incorporating climate projections into technical standards to enhance infrastructure designs. In the transport sector, for example, the United Kingdom has updated its environmental assessment guidance (LA114) and revised its road and bridge design manuals to reflect future climate risks.  In Canada, updated bridge codes now account for shifting patterns in snow loads, rainfall, and temperature. Similarly, in Scandinavia, Norway and Denmark have revised their infrastructure design manuals to address risks from flooding, landslides, and extreme precipitation—mandating formal risk and vulnerability assessments during the planning stage. In Latin America and the Caribbean, several countries are expanding the use of recycled asphalt pavement (RAP) to improve pavement strength and durability while reducing reliance on virgin aggregates and materials (see Box 3.3).

**BOX 3.3.** Paving the Way to More Resilient Roads

Innovative pavement techniques are helping countries reduce emissions, lower construction costs, and improve road durability. One such method is the use of recycled asphalt pavement (RAP), which repurposes materials from end-of-life pavements. By reducing demand for virgin aggregates and cutting transport and disposal needs, RAP offers both environmental and economic benefits. First introduced in the 1970s, RAP is now the predominant paving technique in the United States (Calatayud et al., 2023).

In Latin America and the Caribbean, countries such as Argentina, Brazil, Colombia, and Chile have adopted RAP—primarily to stabilize base layers rather than produce hot asphalt mixes, although the latter offers performance comparable to virgin-material alternatives. Colombia has established national and local regulations governing RAP use, while Brazil has leveraged the technology for over three decades to rehabilitate millions of square meters of roadway. The state of São Paulo, in particular, frequently uses *in situ* cold recycling with Portland cement to restore extensive road networks (Fedrigo, Núñez, and Visser, 2020).

Another promising innovation is the incorporation of rubber powder from end-of-life tires (ELTs) into asphalt mixtures. This approach not only diverts tires from landfills but also enhances pavement strength and durability, while further reducing reliance on virgin materials. In the Latin American and Caribbean region, countries are encouraging adoption through pilot projects, regulations, and procurement incentives. Colombia's National Roads Institute, for instance, awarded higher scores to 4G highway bids that included asphalt rubber. In Brazil, both federal and state specifications support ELT use, with numerous roads built using rubber-modified asphalt in states such as São Paulo, Rio de Janeiro, and Santa Catarina. Chile has also developed technical specifications for rubberized asphalt in its Highway Manual (Section 5.420) and has implemented test segments to evaluate performance (Calatayud et al., 2023).

Notably, investing in resilience is cost-effective. Strengthening materials, improving design standards, and updating building codes may raise initial capital costs only modestly—by about 1–2 percent in the water sector, 3–6 percent in energy, and roughly 5 percent in transport—yet these avert larger future losses. Evidence shows that such investments can yield returns four to seven times their upfront cost (Hallegatte, Rentschler, and Rozenberg, 2019; Barandiarán et al., 2019).

## Maintenance: The Key to Longevity

Adequate maintenance is another underpinning of resilient infrastructure. The consequences of poor maintenance are deficient service quality, operational inefficiency, and threats to public safety. In transport, deteriorating roads contribute to vehicle damage, longer travel times, increased fuel use, and accidents. In the energy sector, poor conservation undermines grid stability, causing energy losses, equipment failures, and, in some cases, fires. In the water sector, insufficient maintenance increases leakages and service disruptions (Cavallo, Powell, and Serebrisky, 2020).[7]

Tight fiscal budgets, weak institutional capacity, corruption, and the absence of contractual incentives to ensure upkeep are factors that drive underinvestment in maintenance. Political economy dynamics are also at play—governments often prioritize new construction projects, which are more visible and politically rewarding, over the less visible work of maintaining existing assets (Serebrisky, Suárez-Alemán, and Pastor, 2018). From an economic perspective, failing to maintain infrastructure is equivalent to misallocating public resources (Pastor, 2020).

Similar to location planning and improving materials and codes, maintenance is also a critical and cost-effective component of resilience. Throughout an asset's lifespan, capital costs represent 15 to 30 percent of total expenses, with the remaining portion going to operations and maintenance (CDRI, 2023). These ongoing costs are essential investments that preserve asset performance and extend infrastructure lifecycle,

7 Despite its critical importance, maintenance is chronically underfunded in the region. Infrastructure is designed to deliver services over decades, but that long service life depends on regular and effective upkeep. When maintenance is deferred or ignored, the social return on investment declines sharply, undermining the efficiency of initial capital outlays (see Cavallo, Powell, and Serebrisky, 2020).

preventing premature deterioration and costly replacements. Neglecting maintenance leads to higher capital replacement needs: according to projections, insufficient maintenance could increase replacement costs by at least 50 percent in the transport sector and 60 percent in the water sector in low- and middle-income countries between 2015 and 2030 (Rozenberg and Fay, 2019).

Good maintenance includes both preventive and adaptive measures aimed at reinforcing existing infrastructure to withstand emerging and intensifying hazards. For instance, managing vegetation around transmission lines reduces wildfire risks to the power grid, while burying cables protects them from cyclones, floods, and landslides (IEA, 2021b). Despite the clear benefits, current maintenance practices often fall short of what is necessary. Data from IDB's AquaRating—a performance evaluation system for water and sanitation utilities—reveal that over half of providers lack formal maintenance and asset replacement plans grounded in risk and cost assessments (Pastor, 2020). Closing these gaps requires increasing investment in maintenance by 40 percent by 2030 (Brichetti et al., 2021). Ultimately, ensuring long-term resilience requires placing maintenance at the core of infrastructure investment, budgeting, and project design—rather than treating it as an afterthought.

## The Need for a Plan B for Service Continuity: Diversification, Decentralization, and Redundancy

The provision of infrastructure services depends on interconnected networks, where disruptions in one part of the system can cascade across others. Ensuring service continuity when parts of a system are disrupted by nature's shocks therefore requires investing in diversification, decentralization, and redundancy.

Diversification refers to the use of multiple, distinct sources or systems to deliver a service, reducing dependence on any single node and, therefore, lowering the likelihood of widespread failure. When one source fails or is compromised, others can compensate, reducing dependence on any node and improving resilience. In the water sector, for example, cities can diversify supply sources to improve the capacity to deliver drinking water during extreme weather events. Santiago de Chile illustrates the point: intense rainfall has increasingly raised turbidity events in the Maipo and

Mapocho rivers, temporarily rendering them unusable for drinking water supply. In response, the utility Aguas Andinas invested in deep wells and large storage ponds to reduce dependence on these rivers, increasing its ability to maintain water supply during rising turbidity events from 4 to 37 hours, with plans to reach 48 hours by 2030 (Solís and Serebrisky, 2023).

Another alternative for diversification of water sources is rainwater harvesting. This involves collecting and storing rainwater from rooftops or other surfaces for domestic use such as cleaning and irrigation, and sometimes, drinking and cooking. Policies supporting rainwater harvesting can help address water scarcity, especially in urban areas. For example, Mexico City's "Cosecha de Lluvia" program has successfully reduced water scarcity in poor neighborhoods, improved welfare for beneficiary households, lowered greenhouse gas emissions associated with centralized water provision in the city, and decreased urban water runoff (Bejarano et al., 2025).

Managed Aquifer Recharge (MAR) can also help reduce pressure on groundwater depletion and promote circular water economy. MAR refers to techniques that involve intentionally replenishing underground aquifers. Also known as "water banking," the strategy relies on the idea that excess water can be stored for use as backup supply during a prolonged drought. Water use for recharging can come from different sources such as rainwater, river flows, dam release or water reuse. Benefits of storing water in aquifers are multiple: it minimizes evaporation losses, reduces contamination risks and avoids proliferation of mosquitoes and toxic algal blooms. For MAR to be effective, it requires a clear policy mandate and regulatory framework, including government recognition—such as the formal inclusion of MAR in water policies and the provision of institutional support—and defined rules for its implementation. In practice, however, progress is often constrained by gaps in hydrological data, weak institutional coordination, and the absence of consistent quality standards.

Additional strategies include the reuse of treated wastewater for non-potable purposes, such as agriculture or industrial cooling, and desalination. In San Luis Potosí, Mexico, the Tenorio treatment plant reuses up to 45 percent of the city's wastewater, easing pressure on groundwater and reducing pollution (World Bank, 2018) (see Box 3.4). Similarly, Chile has implemented desalination plants to remove salt and other impurities from seawater or brackish water, supplying both domestic needs and industrial activities, particularly in the mining sector (Herrera-León et al., 2019).

**BOX 3.4.** Keeping the Water on in San Luis Potosí

San Luis Potosí, Mexico, faces chronic water scarcity due to low rainfall, growing population demands, and expanding industrial activity—all of which place significant pressure on local aquifers. To curb aquifer depletion, groundwater use was restricted as early as 1961, and untreated wastewater began to be used for agricultural irrigation. To further protect water resources and promote safe non-potable reuse, the government launched the Integrated Plan for Sanitation and Water Reuse. A centerpiece of this strategy is the Tenorio Project—the city's largest water treatment plant, in operation since 2006. The plant is notable for its multi-quality treatment approach, supplying reclaimed water for industrial cooling, agricultural irrigation, and environmental restoration. Its financial sustainability is supported through a contractual agreement with a major industrial user.

The water reuse for irrigation from Tenorio WWTP meets the standards established by the Mexican government regarding total suspended solids (TSS), biochemical oxygen demand (BOD), and fecal coliforms with losing adequate concentration in nitrogen or phosphorus.
The water treated for the power plant meets the standards agreed upon with the Federal Electricity Commission (CFE), which are more stringent than those for agriculture irrigation (World Bank, 2018). Maintaining the necessary residual chlorine levels in the conveyance system of the cooling towers was a challenge due to the high flow variation which reflects daily and seasonal variation in energy demand. Producing water of consistent quality was, therefore, a key factor for the success of the project (Lazarova et al., 2013).

The project's total investment cost included a wastewater treatment plant, sewer pipes, a water distribution system, and an irrigation system, financed at 40 percent with public funds and 60 percent from private sources. To ensure sustainability, the State Water Commission

(CEA) signed a first contract with ARTE for the construction and operation of the wastewater plant and another with the Federal Electricity Commission (CFE) for purchasing treated wastewater for the power plant. The agreed fee for the wastewater was 67 percent of the price of groundwater for industrial use (World Bank, 2018). And given that water costs for industry are one of the highest in the country, the agreement benefited both parties by reducing operational costs (for the wastewater treatment plant and for the cooling of the power plant), securing a reliable water supply and significantly alleviating pressure on the aquifer.

In the energy sector, diversifying the electricity generation mix is key to strengthening resilience. Many countries remain heavily reliant on hydropower generation, which can experience sharp output declines during droughts (Gonzalez-Salazar and Roger Poganietz, 2022; Bagnoli et al., forthcoming). For example, droughts in Brazil, Colombia, and Ecuador have led to blackouts, costly electricity imports, and emergency fossil-fuel generation (IMF, 2024; IEA, 2025).[8] Reducing this dependence requires a broader energy portfolio that integrates renewable sources such as solar, wind, sustainable biomass, and geothermal, often supported by storage or hybrid systems that stabilize supply.[9] Well-designed short-term electricity markets and regional integration mechanisms can enhance the value of diversification, allowing countries to better absorb supply shocks (Balza et

8 Ecuador has faced nationwide blackouts since late 2024, following similar events in late 2023, as severe drought, exacerbated by El Niño, cut hydroelectric output and halted imports from equally affected Colombia. In Brazil, a 30-minute storm in October 2024 damaged transmission lines and substations, leaving 2.6 million people without power.

9 Hybrid systems integrate multiple electricity generation methods, typically combining renewable sources like solar panels and wind turbines. By blending different generation types, these systems enhance energy security and reliability. They often include energy storage solutions, such as batteries or fuel cells, or sometimes small fossil-fuel generators, to maintain a consistent and dependable power supply.

al., 2024).[10] In addition, policy tools such as long-term auctions[11] and capacity markets[12] can accelerate this transformation, ensuring more stable and adaptable power systems in the face of growing climate variability.

Redundancy refers to the intentional duplication of critical components or functions of a system to ensure service continuity in case one element fails. In the transport sector, redundancy in inter-urban mobility means providing multiple mobility options—road, rail, water, and air transportation—so that people can travel even if one mode becomes unavailable. In some locations redundancy is critical and requires planning and policy action. For instance, in the Brazilian state of Amazonas, 30 percent of urban communities are accessible only by boat. Severe droughts, such as the 2023 episode, caused river levels to drop drastically, disrupting water transport and cutting off these communities from essential goods and services, including food, fuel, medicine, healthcare, and education. The region's dense rainforests and seasonal flooding further limit the usability of roads and railways for parts of the year, making waterborne transport a critical lifeline. These conditions highlight the urgent need for resilient and diversified mobility strategies, including investments in more reliable river navigation infrastructure, improved intermodal connections—linking fluvial routes with rural roads—and contingency systems to ensure the delivery of basic goods during disruptions. Achieving this requires better transport planning and stronger coordination across both government levels and, where relevant, borders (Cavallo and León-Gómez, forthcoming). In energy systems, redundancy involves distributing generation capacity across diverse sources and locations to prevent widespread outages from localized shocks. Peru is strengthening its resilience by expanding solar power in the south and wind power in the north, which together accounted more than 8 percent of total electricity output in 2024, reducing dependence on any single source or region (EMBER, 2025). Itaipú, one of the world's largest hydroelectric plants,

10 Short-term electricity markets are critical to unlocking the resilience benefits of diversification. As the share of variable renewables grows, systems face greater volatility in supply, which must be matched by flexibility on the demand, generation, and storage sides. Price volatility, often seen as a problem, is in fact a key mechanism for signaling scarcity and rewarding flexible resources. When market rules cap prices too tightly or mute these signals through regulatory interventions, investments in storage, demand response, and backup capacity are discouraged. Instead, allowing prices to fluctuate helps ensure that systems are both efficient and resilient in the face of climatic shocks (Balza et al., 2024).

11 Long-term auctions refer to competitive bidding processes where electricity producers commit to supplying power over an extended period, often several years, at a fixed price.

12 Capacity markets are mechanisms where power producers get paid not just for the electricity they generate but also for maintaining available capacity to supply electricity when needed, especially during peak demand or emergencies.

jointly owned and operated by Brazil and Paraguay provides electricity to around 80 million people, providing a stable and reliable renewable energy source that complements other energy sources in the region.

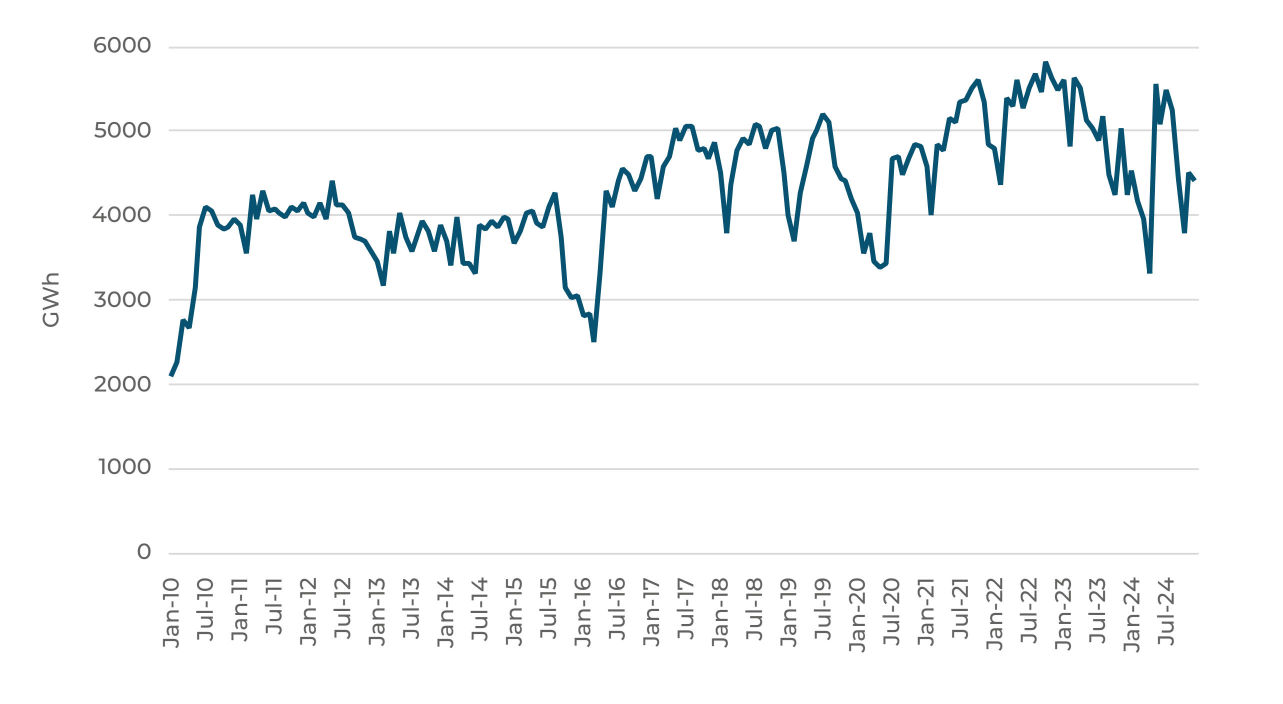
Decentralization complements diversification and redundancy by reducing reliance on infrastructure that is vulnerable to localized disasters and shocks. It involves distributing the provision and control of services across multiple sites or administrative units, rather than concentrating them in a single location. At the same time, regional integration acts as a complementary strategy to system resilience. Cross-border electricity trade expands the geographic footprint of supply, allowing countries to share resources and smooth the variability of supply during certain climate events. Interconnection also reduces the cost of backup capacity by pooling reserves across multiple systems. For example, the bilateral power interconnection between Colombia and Ecuador has improved energy resilience when hydropower output declines during prolonged droughts (see Box 3.5). Similarly, in the water sector, placing small-scale water treatment facilities within neighborhoods, rather than relying solely on a central plant, enhances a city's ability to maintain service during emergencies and enables faster recovery.

**BOX 3.5.**

## Good Neighbors: Colombia–Ecuador Electricity Interconnection

Regional market integration has proven essential for managing climate-driven supply risk in Latin America and the Caribbean. Figure B3.5.1 presents Colombia's monthly hydroelectric output in gigawatt-hours from January 2010 through December 2024. During this period, hydro accounted for over 70 percent of generation. Three patterns emerge. First, mean output rose from roughly 3,500–4,500 GWh per month before 2015 to more than 5,000 GWh per month by 2020, reflecting capacity expansions. Second, strong seasonality appears in wet-season peaks between March and May and dry-season troughs from September to November. Third, extreme droughts in 2016, 2019–2020, and 2023 triggered sharp output declines. To address these shortfalls, Colombia deploys two supply-side mechanisms. It increases thermal-generation to cover lost hydro output and imports electricity from Ecuador.

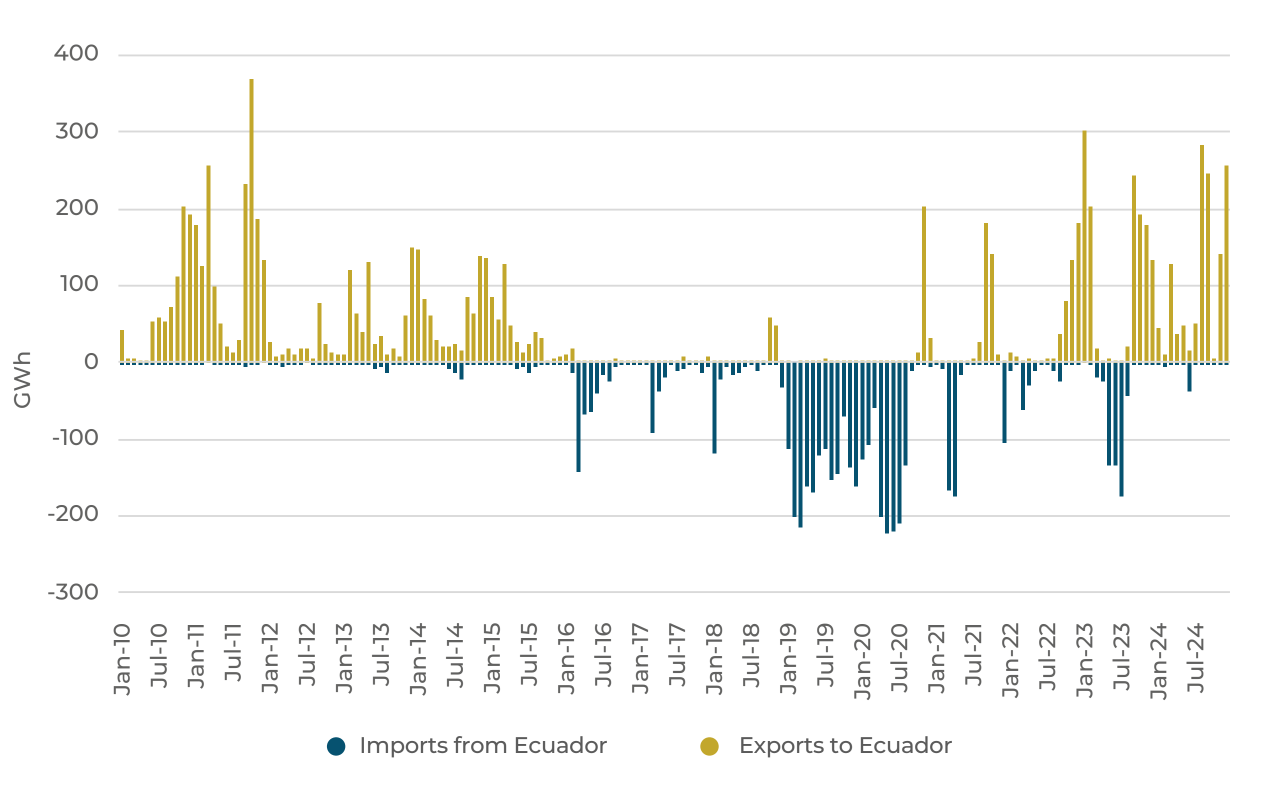
**Figure B3.5.1.**
Colombia's Electricity Trade with Ecuador: Exports and Imports




**Source:** Authors' elaboration based on data from Sinergox Colombia.

Figure B3.5.2 indicates that electricity imports from Ecuador become material for Colombia only during episodes of market stress—most recently in 2016, 2019-2020, and 2023. The pattern is mirrored from Ecuador's side: its predominantly hydro-based system (hydropower has supplied more than 70 percent of generation over the past decade) generally enables exports, but leaves the country exposed when water shortages arise. During the 2024 drought, for example, Ecuador had to reverse the usual flow and draw on Colombian power to satisfy domestic demand. These episodes highlight cross-border interconnection as an ex-ante investment in resilience, allowing both systems to buffer weather-driven supply shocks that are becoming more frequent with climate change. Integration efforts continue to deepen, with Ecuador pursuing additional links to Peru and Colombia, and Colombia progressing on a new interconnection with Panama.

**Figure B3.5.2.**
Colombia's Electricity Trade with Ecuador: Exports and Imports




**Source:** Authors' elaboration based on data from Sinergox Colombia.

## Back to Nature

Nature-based solutions (NBS) are interventions that protect, restore, or sustainably manage ecosystems, providing effective and cost-efficient tools to strengthen infrastructure systems. By leveraging natural processes, NBS offer complementary, or alternative, options to traditional “grey” infrastructure, supporting service delivery, climate adaptation, and risk reduction while also providing environmental and social co-benefits (IPCC, 2022; Ozment et al., 2021; Cavallo, Powell, and Serebrisky, 2020).

Ecosystem-based adaptation approaches—such as forest conservation, wetland restoration, and watershed protection—help mitigate flooding, reduce erosion, and safeguard water supplies. For example, forested catchments increase water retention, decrease sedimentation, and help utilities cut treatment costs (Caldwell et al., 2023). Policy instruments like Payments for Ecosystem Services (PES) and land-use regulations provide financial and legal incentives. Costa Rica offers a notable example of how regulatory frameworks can institutionalize NBS: the Urban Planning Law (Law 4240) requires land-use plans to allocate areas for public spaces, parks, and green zones, and obliges developers to transfer land free of charge to municipalities, ensuring that urban growth incorporates nature-based infrastructure (Programa de Corredores Biológicos de Costa Rica, 2021).

Stormwater management is another area where NBS have demonstrated potential. With floods and extreme rainfall events accounting for over 60 percent of damage in the water sector, Latin American and Caribbean cities are adopting solutions that integrate green and grey infrastructure (Balza et al., 2025). These include bioswales, which slow and filter runoff from streets; green roofs, which absorb rainfall and reduce pressure on drainage systems; and retention ponds, which temporarily store excess water to prevent flooding. Beyond managing runoff, these solutions offer multiple co-benefits—enhancing urban biodiversity, improving air quality, reducing heat, and creating accessible green spaces for residents (Oliver et al., 2021). Table 3.1 outlines specific examples of how NBS complement or substitute grey infrastructure across key processes in water and sanitation services.[13] The use of NBS is growing in Latin America and the Caribbean. A survey of 61 water operators in 11 countries found that while 36 percent have yet to adopt NBS, 43 percent are actively investing in upper watershed reforestation, and 30 percent in restoring ecosystems such as lakes and wetlands (Solís and Serebrisky, 2023).

13 See Oliver et al. (2021) for further examples in the sectors of transport and energy.

**Table 3.1.**
Grey Infrastructure and Nature-Based Solutions in Water and Sanitation Services

| PROCESS | GREY INFRASTRUCTURE | NATURE-BASED SOLUTIONS | |
|---|---|---|---|
| | | NATURAL / GREEN INFRASTRUCTURE | ECOSYSTEM BENEFITS |
| WATER TREATMENT | Water treatment plant | Forestland, riparian areas surrounding water sources, mangroves | **Water quality regulation:** They naturally filter biological and chemical impurities, trap sediment and reduce erosion. |
| INCREASE IN WATER AVAILABILITY | Water transfers | Forests, wetlands, floodplains | **Water availability:** During dry periods they increase storage capacity, improve base flows, and enhance water quality. |
| STORAGE | Reservoirs, dams | Aquifers | **Water storage:** Aquifers turn unstable phenomena such as rainfall into a stable water source. |
| STORMWATER MANAGEMENT | Stormwater drainage system | Green roofs, porous pavements, wetlands, bioswales, rain gardens | **Aquifers recharge and urban flood management:** Water infiltration in the ground, overflowing and flooding prevention |
| WASTEWATER TREATMENT | Wastewater treatment plant | (Constructed) wetlands | **Treatment:** Wastewater natural treatment reducing treatment needs. |

**Source:** Balza et al. (2025) and Oliver et al. (2021).

A growing body of evidence on cost-effectiveness and co-benefits supports the case for NBS. In São Paulo, where recurring droughts have placed growing pressure on water supplies, Ciasca et al. (2023) estimate that the economic losses of the 2014–2015 drought ($316 million) could have been reduced by 28 percent had nature-based solutions been in place. Similarly, protecting upstream forests helped New York City avoid building a water treatment plant estimated at $8–10 billion (Abell et al., 2017).

In the transport sector the uptake of NBS is growing through pilot programs. For example, Chicago's Green Permitting Process accelerates approval for projects incorporating rain gardens and permeable pavements (US EPA, 2023). Ljubljana has expanded green spaces to improve urban cooling and promote active mobility (Oppla, 2023). Along coastlines, natural buffers like dunes, mangroves, and wetlands are increasingly being used to shield road networks from storm surges and erosion—an approach promoted by the U.S. Federal Highway Administration (FHWA, 2019).

Ultimately, the success of NBS depends on context, supportive regulations, and financing. While the issue of financing is the subject of chapter 4, suffice it to say that mechanisms are already being implemented in the region and elsewhere to support NBS. For example, in Peru, the Water Regulation Authority allocates a share of water tariffs to finance a growing portfolio of watershed restoration projects across the country (Benites Elorreaga and Gammie, 2021). And Germany provides subsidies for green roofs and facades to reduce urban heat and runoff (European Commission: Directorate-General for Research and Innovation, 2022).

## Adapting Consumer Behavior

Resilient infrastructure also requires demand-side policies that encourage consumers to efficiently use water, electricity, and transportation, thereby easing pressure on existing systems. Policies to manage demand include pricing mechanisms to create long-term incentives for efficient resource use, information campaigns and behavioral nudges to raise awareness or make sustainable choices more appealing, and early warning systems that prompt rapid behavioral adjustments in emergency situations.

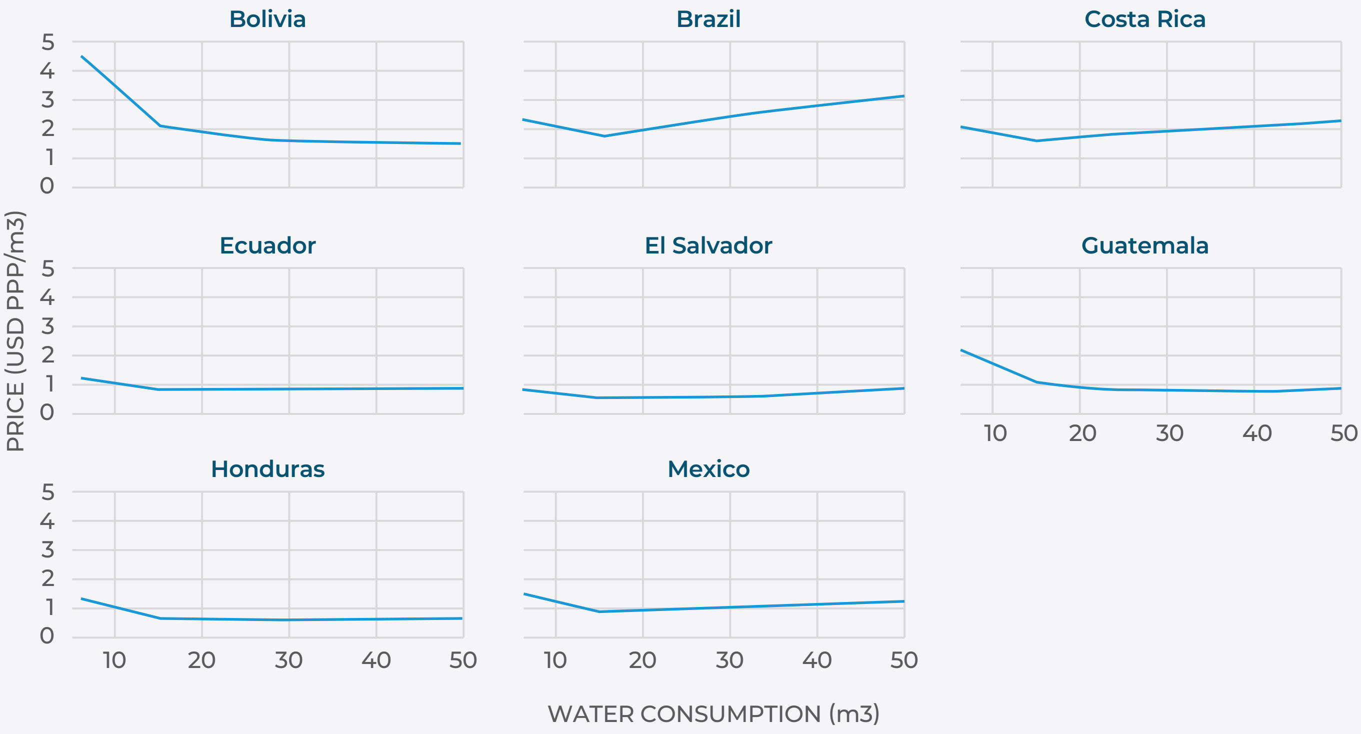
Effective interventions must be tailored to the capacities and contexts of different user groups. The following subsections explore three key approaches to shaping demand.

### Making Sure the Price Is Right

Like in other markets, pricing mechanisms are a powerful tool to influence consumer behavior, encourage efficient resource use, and achieve other objectives like cost recovery in infrastructure service provision. However, implementing the right pricing mechanisms in the infrastructure sphere is easier said than done. Setting the prices right requires effective regulatory institutions, accurate data to align incentives with market dynamics, and adequate technology. Generally, complexity increases in proportion to the strength of incentives needed to encourage consumer participation.

In the water sector, one widely used pricing mechanism is the Increasing Block Rate (IBR) structure, in which the price per unit of water increases as consumption exceeds specific thresholds. But the devil is in the details of implementation. In the region, most tariffs follow a two-part structure with a volumetric component, often designed as IBR and a fixed charge (López-Ruiz et al., 2024). While IBR incentivizes conservation by penalizing high usage, the fixed charge can offset this effect. The average unit price of water in several countries initially declines with rising consumption due to the fixed component in the tariff, before increasing once the volumetric charge dominates (see Figure 3.1). Another pricing mechanism to manage consumption is adjusting tariffs based on seasonal demand variations. Chile, for example, charges higher rates during high-demand summer months and lower rates during off-peak periods (Molinos-Senante and Donoso, 2016). This helps providers reflect the seasonal costs of water supply in the tariff and encourage consumer conservation when resources are most limited.

**Figure 3.1.**
Average Price of Water for IBR Structures in Different Countries




**Source:** Authors' elaboration based on IDB-OLAS, 2024.

Alternatively, Allocation-Based Rates (ABR), or water budget-based rates, set personalized consumption limits for indoor and outdoor use of water. Under ABR, each household receives a "water budget" that reflects the amount it can use efficiently based on household size, lot size, and local climate conditions.[14] Utilities typically adjust water budgets each billing cycle to account for changing weather, such as higher allocations during hotter months when outdoor watering needs increase. Households that stay within their budget pay a standard, lower rate, while those exceeding their budget are charged progressively higher rates. This approach creates a direct financial incentive to conserve water, particularly for high-use households. Studies from California show that ABR adoption significantly reduced consumption among such households (Pérez-Urdiales and Baerenklau, 2019), though successful implementation requires detailed household-level data and measurements of local evapotranspiration.[15]

Advanced metering infrastructure (AMI), such as smart meters, expand pricing options by providing real-time consumption data. Widely used in the water and energy sectors, they enable dynamic pricing that shifts demand to off-peak hours, improves billing accuracy, detects leaks and outages, and delivers timely service information. For instance, in California, smart meters contributed to a reduction in non-revenue water losses from 6 percent to 2 percent of total system input volume and saved 236 million gallons over two years of severe drought (Donnelly and Cooley, 2015).

A complementary tool to pricing mechanisms to promote efficient water use is the wastewater reuse certificate (WRC) system. Inspired by emissions trading and carbon markets, WRCs established water reuse targets for large consumers, such as large industries, industrial parks, housing complexes and gated communities. They also promote the transfer of treated wastewater to other users, such as the agricultural sector, which may face challenges in meeting their targets. In essence, the system allows users who exceed their reuse targets to earn WRCs, which can be traded with those who do not meet their goals.

Finally, in periods of acute water scarcity, emergency incentives such as temporary tariff discounts or penalties can reinforce conservation efforts while supporting broader long-term strategies (see Box 3.6).

14 Water use efficiency is defined as the minimum amount of water required to achieve a given purpose (Gleick, 2004). While Frontier Analysis measures efficiency across households, in practice it is assessed by the water agency, reflecting an engineering rather than economic perspective (Pérez-Urdiales and Baerenklau, 2019).

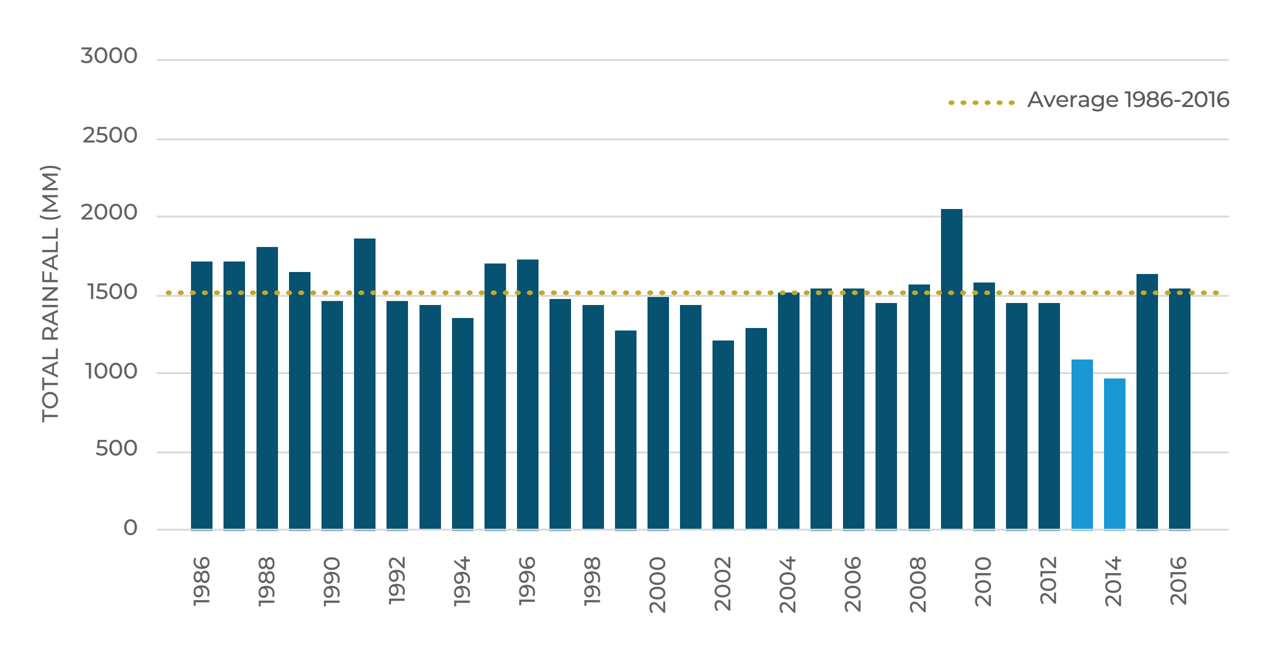
15 Evapotranspiration refers to the amount of water lost to evaporation and plant transpiration.

**BOX 3.6.**

## Dealing with the 2014-2015 Water Crisis in São Paulo

The São Paulo Metropolitan Area (SPMA) is one of the largest metropolitan areas in the world with a total population of 23.4 million (Brazilian Institute of Geography and Statistics, 2025). Due to contamination of nearby sources, water must be collected from distant reservoirs to meet the high demand. The region relies on an extensive network of aqueducts, pipelines, and six reservoir systems: Tietê, Guarapiranga, Cotia, Rio Grande, Rio Claro and Cantareira. The Cantareira System is the largest of them, providing 46 percent of the SPMA water supply (Brazilian National Water Agency, 2025).

**Figure B3.6.1.**
Total Annual Precipitation in Cantareira Reservoir (1986-2016)




**Source:** Authors' elaboration based on data from Department of Water and Electrical Energy, 2025.

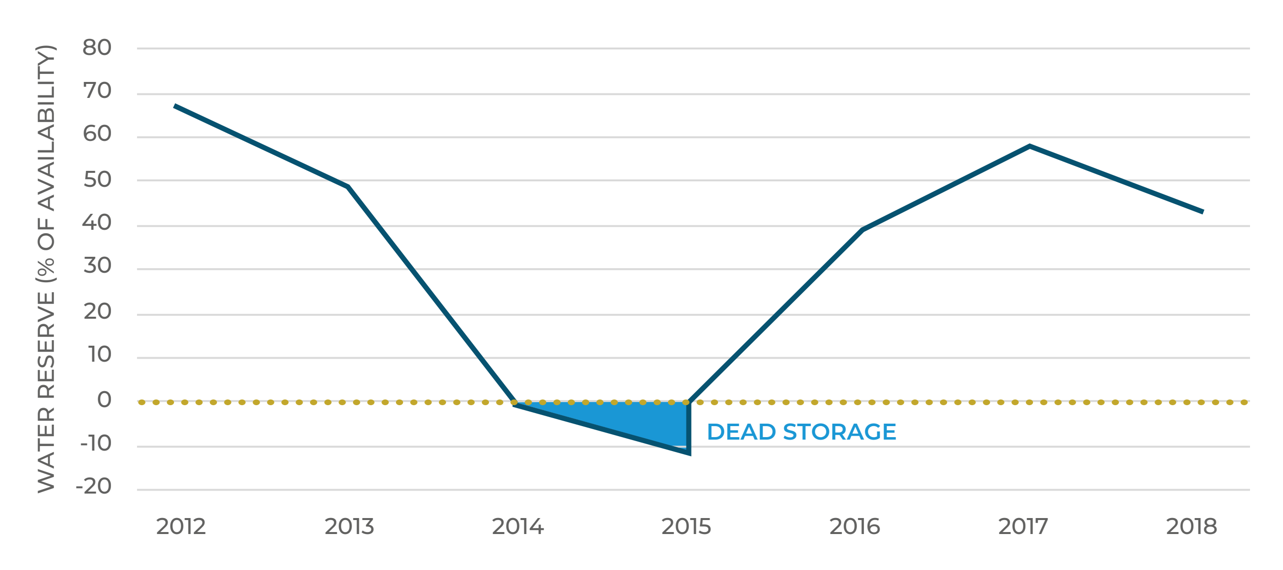
In 2013 and 2014, the SPMA experienced its most severe drought in history, which significantly impacted the Cantareira Water System (Figure B3.6.1). The drought was part of a regional drought, and the result of a new climate reality that differed from the rainfall levels for which the reservoir was originally planned (Zuffo et al., 2023). To mitigate the impact of the drought on the population and economy in the metropolitan area, Sabesp, the major water and sanitation utility serving SPMA, developed a plan that addressed both supply and demand.

### Supply Side

On the supply side, emergency civil works were conducted to maintain a non-stop water supply. These included installing floating pumps, channels, and cofferdams, interconnecting production systems, and extracting water from "dead storage" (water below the usual minimum operational level) (Braga and Kelman, 2020). To ensure water availability for the population, the Cantareira reservoir had to use its "dead storage", dipping to 24 percent below its normal operational level (Figure B3.6.2).

Due to the reservoir's low level, the SPMA, which used to pump 67.8 $m^3/s$ in 2013, shrank to 51.0 $m^3/s$—a 24.7 percent decrease. In particular, Cantareira's pumped water dropped from 32.5 $m^3/s$ to 14.0 $m^3/s$.

**Figure B3.6.2.**
Water Availability in Cantareira Reservoir (2012-2018)




**Source:** Authors' elaboration based on data from Department of Water and Electrical Energy, 2025.

## Demand Side

On the demand side, the company focused on reducing leakages by installing pressure relief valves (PRVs). These valves help lessen pressure in times of lower demand, alleviating leaks and eventual damage to pipes and other structures. Other actions to reduce leakage included replacing water mains, conducting acoustic sweeps to locate leaks, and connecting pipes to households. Together, these actions helped reduce leakage by 7.6 m3/s (Braga and Kelman, 2020).

Additionally, campaigns with financial incentives ("carrot and stick") to reduce water consumption were introduced. Sabesp offered a discount (bonus) on water bills for customers who saved water and imposed a contingency tariff on those who increased their consumption. The bonus tariff had three phases. Phase one, started in February 2014, targeted São Paulo City residents served by the Cantareira System. Customers who cut their average consumption by at least 20 percent compared to the previous year received a 30 percent discount. Phase two, starting in April

2014, expanded the discount to customers outside SPMA that received water from Cantareira. Phase three, starting in November 2014, revised and expanded the incentives to 31 municipalities. Customers lowering their consumption by 10-15 percent received a 10 percent discount, those who cut 15-20 percent enjoyed a 20 percent discount, and reductions over 20 percent received a 30 percent discount. The contingency tariff, introduced in February 2015, applied a 40 percent surcharge on the water bill of customers who increased consumption by less than 20 percent (based on their average consumption from February 2013 to January 2014). For those exceeding 20 percent, the increase was 100 percent. Both the bonus and contingency tariff applied to all customers and were discontinued in March 2016 (Sabesp, 2015b).[16]

The bonus initiative was highly successful, with over 80 percent of consumers participating in and reducing their water usage. In 2014, 49 percent of consumers received the discount, rising to 70 percent in 2015. The contingency tariff was applied to 19 percent of consumers (Braga and Kelman, 2020).[17] Together, the actions led to a 23 percent reduction in water production in SPMA, attributed as follows: 8.6 percent to leakage reduction, 5.6 percent to financial incentives aimed at reducing consumption, and 2.5 percent related to cuts in other utilities that also serve the metropolitan area (Sabesp, 2015a). Importantly, the design and timing of the incentives may also affect the results (Zetland, 2021).

In the energy sector, dynamic pricing mechanisms are increasingly used to manage demand and strengthen system resilience. One example is Time-of-Use (ToU) pricing, which divides the day into fixed periods with varying rates to reflect demand patterns. Seasonal pricing works similarly, with higher rates during peak-demand months and lower rates in off-peak periods, encouraging consumers to shift their consumption away from system stress. Similarly, Critical Peak Pricing (CPP) temporarily raises rates during periods of high wholesale electricity prices or system stress, while

16 Customers with water consumption equal to or below 10m³, hospitals, first-aid clinics, nursing homes, police stations, and prisons were all exempt.

17 This includes customers using less than 10 m³ per month (some 8 percent of consumers), but for whom the tariff was not applied (Braga and Kelman, 2020).

Critical Peak Rebate (CPR) rewards customers for restricting usage at such times. While CPR proves more acceptable to consumers, it requires granular data on individual consumption patterns and sophisticated metering infrastructure to measure and verify demand reductions.

Real-Time Pricing (RTP) is a pricing mechanism that links retail rates directly to wholesale market conditions, varying hourly or daily and communicated shortly before taking effect. By reflecting supply and demand in real time, RTP help balance the grid, reduce outage risks, and improve affordability during climate-driven price spikes. Alternatively, Variable Peak Pricing (VPP) offers a hybrid approach, combining predictable off-peak tariffs with peak-period rates that vary according to market conditions. VPP blends the benefits of ToU and RTP by balancing responsiveness with consumer predictability. Simpler mechanisms like CPP and CPR provide limited incentives but are easier to implement, whereas RTP and VPP create stronger incentives for behavioral change but require greater infrastructure and operational complexity.

Uruguay provides a practical example of these approaches in action. The national utility, Administración Nacional de Usinas y Trasmisiones Eléctricas (UTE), has deployed smart meters that record electricity consumption every 15 minutes, enabling dynamic tariff pricing without requiring on-site meter readings. These meters also detect connection faults, service interruptions, and issues in internal installations (UTE, 2025). All residential tariffs are structured so that higher consumption leads to higher charges. They include incentives to shift usage to off-peak hours to improve distribution network efficiency, with double-hour and triple-hour rates during on-peak periods. Additionally, residential consumers have access to four tariff schemes, depending on their contracted power and variable consumption needs (Aboal et al., 2020).

Despite the potential of the various pricing mechanisms, their impacts on total water and energy consumption are constrained by the inelastic nature of demand. This implies that significant price increases are often needed to meaningfully reduce consumption. Moreover, strong equity and social concerns frequently limit the extent to which prices can be raised, as higher costs may disproportionately affect low-income and vulnerable populations, making widespread implementation challenging. Therefore, most of the time, pricing mechanisms are more effective at shifting usage to off-peak periods than at lowering overall demand.

Pricing mechanisms send signals to consumers. Other incentive-compatible mechanisms can also affect private investment. Insurance premium adjustments that reward investments in resilient infrastructure, performance-based financing mechanisms that link disbursements to verified climate outcomes, and dedicated adaptation funds or contingency reserves that enable rapid recovery following disasters are tools that provide incentives to private investors. Other mechanisms, such as grants for R&D, subsidies for technologies like desalination or rainwater harvesting, and payments for environmental services—for example, catchment protection or aquifer recharge—also incentivize proactive adaptation measures.

Insurance mechanisms play a particularly important role in supporting resilience. Both formal instruments (e.g., reinsurance, risk pooling, and infrastructure-specific coverage) and informal mechanisms (e.g., post-disaster aid or climate risk disclosures) reduce financial losses from extreme events while encouraging resilience investments. In the energy sector, index-based insurance triggers payouts when predefined climate thresholds are reached, such as extreme wind speeds or wildfire risk, allowing faster responses and reducing moral hazard. While uptake remains limited in developing regions (Chambwera et al., 2014), regional pooling facilities like the Caribbean Catastrophic Risk Insurance Facility (CCRIF)[18] illustrate how shared coverage for energy-related disasters, such as hurricanes that damage power grids, can lower premiums and strengthen sector-wide resilience. However, the disaster insurance protection gap is widening: currently, 62 percent of global economic losses from natural catastrophes are uninsured. Of concern is that climate change threatens insurance accessibility; some regions and businesses may become effectively 'uninsurable' due to rising costs and limited coverage (Glemarec, Solana, and Babinsky, 2025).

## Nudging for Smarter Consumption

Information, awareness, and subtle behavioral cues—commonly referred to as nudges—can also impact consumption. These non-coercive approaches can promote sustainable water, energy, and transport use without imposing significant costs on consumers or governments.

18 CCRIF SPC limits the financial impact of natural hazard events to Caribbean and Central American governments by quickly providing short-term liquidity when a policy is triggered. CCRIF offers parametric insurance policies for tropical cyclones, earthquakes, excess rainfall, to the fisheries sector and the electric and water utilities sectors.

Public awareness campaigns are used to encourage water conservation. These can range from media coverage during droughts, as seen during the California drought (Quesnel and Ajami, 2017), to long-term educational initiatives. In Mexico, the Institute for Water Technology (IMTA) has run school-based awareness campaigns since the 1990s. Mexico City has also adopted outreach tools such as posters ("El Decálogo del Agua") and video-based campaigns under its "Culture of Water" initiative (Boyes and Andersson, 2023).

Behavioral nudges—which change the way information is presented to influence decisions—have also proven effective. For example, during the 2015–2018 drought in Cape Town, South Africa, the city faced the threat of running out of water by 2018. In response, they launched the high-profile Day Zero campaign that combined conservation messages on monthly water bills, water-saving tips, competitions, and frequent public updates tracking progress toward delaying the cutoff date. Residents were urged to limit water use to 50 liters per day, take short showers, flush toilets only when necessary, and avoid using drinking water for gardening. Thanks to these measures, Cape Town reduced water consumption by nearly 60 percent compared to 2015 levels by late 2018, successfully averting Day Zero and curbing the crisis (Schreiber, 2019).

Technologies like gamified platforms are expanding the possibilities for engagement. In Singapore, the National Water Agency (PUB) partnered with the utility SUEZ to develop *WaterGoWhere*, a pilot app that uses smart meters, analytics, and gamification to engage residents. Users receive personalized challenges, track their consumption, and earn rewards for reducing usage. This approach achieved estimated savings of 5 percent, driven by leak detection and customer engagement initiatives that lowered per capita daily water use by nearly 7 liters (Wong et al., 2019).

Artificial intelligence (AI) is transforming how utilities collect, analyze, and utilize digital information. For example, smart meters leverage AI to provide granular, real-time consumption data and continuous monitoring, enabling utilities to detect faults, identify leaks, reduce non-revenue water, and quickly spot service outages. AI-driven virtual models further enhance operations by simulating network performance, forecasting shortages, and supporting planning under changing climate conditions (Enriquez et al., 2023). These technologies enable dynamic information flow, like instant price alerts, helping customers make timely, informed decisions. By lowering the costs of demand-response transactions and enabling rapid responses to real-time signals, these measures increase operational flexibility and efficiency (Cavallo, Powell, and Serebrisky, 2020).

Water- and energy-efficient appliances offer cost-effective ways to reduce resource waste. Dual-flush toilets and low-flow showerheads have significantly lowered household water use (Attari, 2014), while efficient air conditioners, freezers, and refrigerators help save electricity. Rebates and mandatory labeling can accelerate adoption of energy efficient appliances. For example, Australia's Water Efficiency Labelling and Standards (WELS) program has reduced household water consumption since 2005 by requiring standardized efficiency labels on water-using appliances (see Box 3.7). Similarly, energy labeling in the European Union has effectively increased the market share of efficient refrigeration appliances (Schleich et al., 2019; Bjerregaard and Møller, 2019).

**BOX 3.7.**

## Efficiency Labelling

Water efficiency labels and standards have been shown to significantly reduce water consumption, as evidenced by the experiences of Australia, the European Union, and Singapore.

Established in 2005, the Water Efficiency Labelling and Standards (WELS) scheme in Australia has effectively reduced water usage by labeling water-efficient products (see Figure B3.7.1). This program mandates water efficiency labeling for indoor water-using appliances and fixtures and sets minimum standards for other devices. The labels use a six-star rating system to categorize water efficiency, with more stars indicating higher water efficiency. The labels also display information on water consumption or flow rate (Kelly, 2015). The impact of the WELS scheme has been substantial. It has achieved 112 GL/year in water savings across Australia, with projections of 185 GL/year by 2026 and 231 GL/year by 2036. Additionally, the program has generated total benefits exceeding $17.3 billion through savings in water, electricity, natural gas, and greenhouse gas emissions (Fane, Grossman, and Schlunke, 2020).

A similar scheme was introduced in Singapore as part of the national water agency's water conservation efforts. While the scheme was first voluntary, it became mandatory for taps, cisterns, toilet flush valves, washing machines, and dishwashers, among others. The WELS label uses a three-tick rating system to show the overall level of water efficiency of the product: one tick (good), two ticks (very good), and three ticks (excellent). A zero tick is assigned to devices that are not water efficient. The label also displays how much water is consumed by the device. This policy, together with other pricing and non-pricing policies, has resulted in a decrease in per capita water consumption from 172 l/day in 1995 to 147 l/day in 2011 (Tortajada, Joshi and Biswas, 2013).

**Figure B3.7.1.**
Water Efficiency Labels from the WELS Programs in Australia and Singapore


**Source:** Water Rating of the Australian Government and Singapore's National Water Agency (PUB).

## Ready for Disaster with Early Warning Systems

Early warning systems (EWS) are critical tools to prepare infrastructure systems for disasters and to protect the population. By integrating data collection, hazard forecasting, risk assessment, and timely communication, these systems enable individuals, communities, and authorities to take preventive action before disasters strike. EWS benefits include faster emergency response, reduced mortality, and efficient resource allocation once the disasters hit. Their effectiveness depends on technological capabilities and on institutional coordination, public trust, and the ability to reach populations at risk.

Digital technologies play a decisive role in strengthening EWS. Innovations such as the Internet of Things (IoT), AI, and cloud computing allow for real-time monitoring and forecasting by collecting, analyzing, and disseminating data. These tools improve both the accuracy and timeliness of alerts, enabling authorities to issue warnings earlier and with greater precision (Esposito et al., 2022; Rogers and Tsirkunov, 2010). For instance, telemetric systems and satellite imagery are increasingly used to track water availability and quality that can be compromised during droughts, floods, and rising temperatures. EWS are cost-effective. Hallegatte (2012) estimates that in Europe, hydro-meteorological EWS save several hundred lives annually, prevent between 460 million and 2.7 billion Euros in disaster asset losses, and generate an additional 3.4 to 34 billion Euros annually by optimizing production in weather-sensitive sectors such as agriculture and energy. In developing countries, these benefits may be even greater due to larger populations, higher hazard risks, and greater vulnerabilities linked to weaker infrastructure.

EWS can be supported through a range of national and international mechanisms including grants, concessional loans, bonds, and targeted government programs (see UNDRR and WMO, 2023). Since 2011, Brazil's CEMADEN (National Center for Monitoring and Early Warning of Natural Disasters) has monitored environmental risks and issued alerts for floods, landslides, and flash floods across 958 municipalities (dos Santos Alvalá et al., 2019). Other countries have benefited from international initiatives like the Climate Risk Early Warning Systems (CREWS), which provide financial and technical assistance to enhance forecasting capabilities and train hydrometeorological services.

## Planning, Institutions, and Alliances for a Resilient Future

Planning to set long-term goals, coordinate investments, and promote coherence across different levels of government, plays a pivotal role in building resilience and enabling countries to respond proactively to natural shocks. For instance, in the case of droughts, it includes developing an emergency plan, establishing criteria for drought-related actions, setting up early warning systems, and securing agreements for secondary water sources (Barandiarán et al., 2019).[19]

A key function of well-functioning planning institutions is to translate resilience objectives into cross-sectoral action plans (see Box 3.8). For example, planning for a diversified and decentralized energy mix can reduce vulnerability to climate shocks across economic sectors. It can also yield benefits such as reducing pollutant emissions, fostering local green industries, expanding energy access to the population, and strengthening energy security.

**BOX 3.8.** 

### Resilience Prioritization Within Subsector Plans

In the transport sector, national strategies are embedding adaptation into both infrastructure planning and operations. The U.S. Department of Transportation's Strategic Plan (2022–2026) sets a target for half of U.S. states to develop resilience improvement plans by 2026. In Scotland, the National Transport Strategy explicitly addresses climate threats—such as erosion, landslides, and sea-level rise—particularly for vulnerable communities, while highlighting the economic costs of inaction.

Water-sector planning documents are increasingly embedding climate-resilience measures across governance, investment, and

19 See Barandiarán et al. (2019) for detailed risk mitigation options for every type of hazard.

operations. In Victoria, Australia, the Water Cycle Climate Change Adaptation Action Plan (2022–2026) promotes supply diversification, infrastructure upgrades, operational resilience, and community engagement to enhance system-wide water security.

In the energy sector, planning efforts increasingly focus on ensuring the reliability and security of the electric power grid while advancing broader resilience objectives. In Colombia, the Integrated Plan for the Management of Climate Change in the Mining-Energy Sector (*Plan Integral de Gestión del Cambio Climático del sector Minero-Energético,* PIGCCme 2050) seeks to align national energy and climate policies to enhance competitiveness and sustainability, support industry adaptation, and foster collaboration with academia and society. Its strategic priorities include strengthening infrastructure, improving planning and management, and generating data to guide decision-making to meet national climate and energy goals by 2050.

To advance these objectives, policy design and planning should incorporate economic metrics that capture the potential impacts of service disruptions. One such metric is the Value of Lost Load (VoLL), which estimates the economic losses from unmet electricity demand. In urban commercial and industrial areas of Latin America and the Caribbean, outages can translate into losses of tens or even hundreds of thousands of dollars per day for a single facility, underscoring the high stakes involved.[20] Embedding such indicators into planning enables institutions to prioritize investments where disruptions would entail the greatest economic costs, aligning resilience goals with sound economic decision-making.

Countries with successful planning institutions often establish coordination mechanisms—typically inter-ministerial committees—to set priorities, define joint action plans, and harmonize sectoral interventions. Examples include the United Kingdom's Inter-Ministerial Group on Transport, which includes climate representation, and Singapore's Inter-Ministerial Committee on Climate Change, which incorporates transport planning. The success

20 For example, outages in manufacturing hubs or financial districts in Latin America and the Caribbean can lead to losses exceeding $10,000 per MWh, while residential sectors may experience lower but still significant impacts. (Yépez-García and Jiménez-Mori, 2024)

of planning institutions depends on political leadership, clear mandates with decision-making authority, well-defined milestones, and the active engagement of the private sector and civil society (Calatayud et al., 2023).

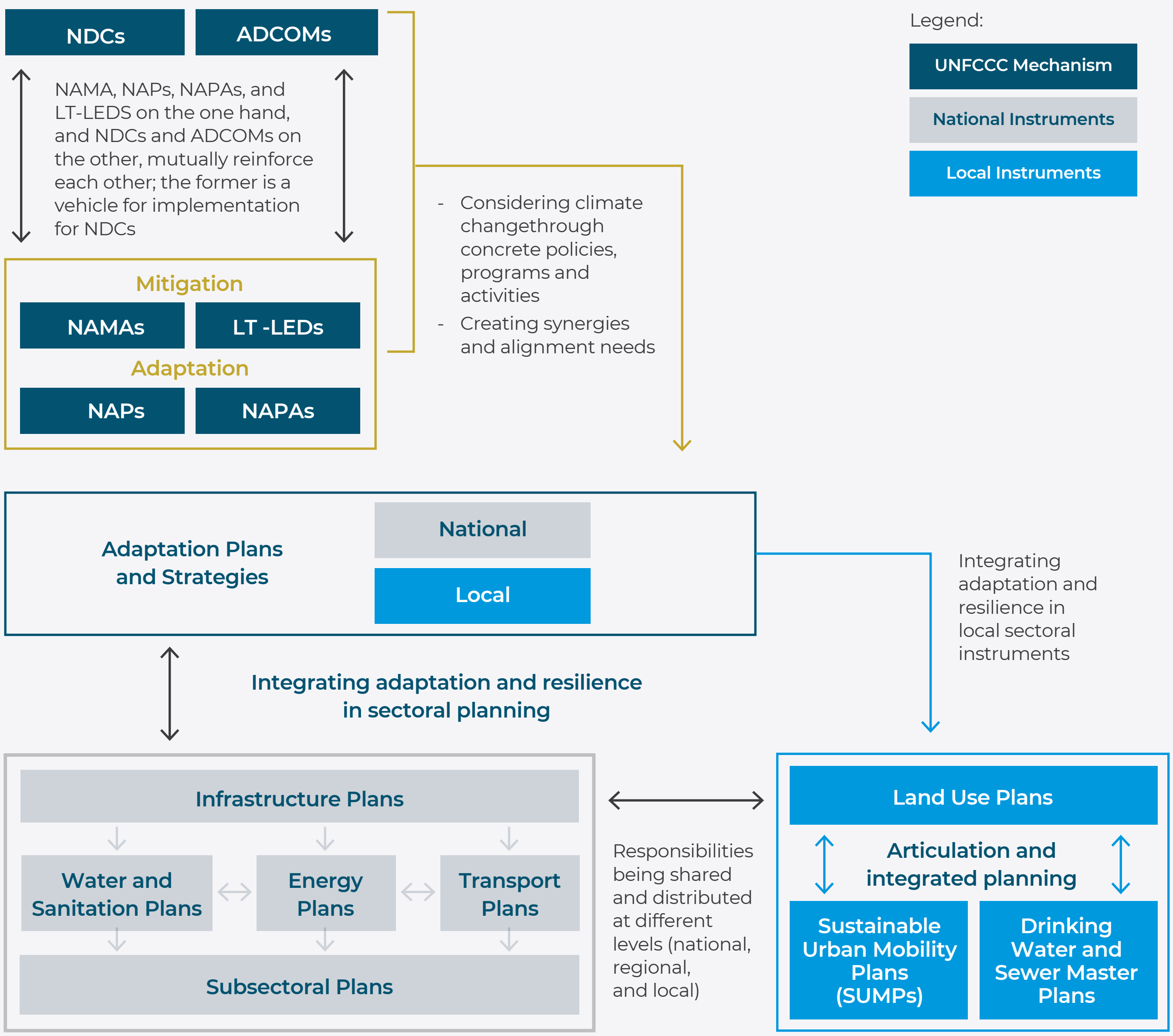
Good planning also requires coordination among national, regional, and local governments. National governments, together with national public investment systems, play a central role by setting regulatory frameworks, strengthening institutional capacity, and fostering collaboration across tiers of government. This is crucial for mainstream planning throughout all levels of administration. Italy's port governance model offers an example of this multi-level approach: the Ministry of Transport provides strategic oversight, port authorities handle planning and development, and private concessionaires manage daily operations. Port committees, which include elected officials from all levels of government as well as industry stakeholders, help ensure coherent implementation and decision-making aligned with common objectives.

Strategic alliances with non-state actors complement intra-government coordination by enhancing climate-resilient infrastructure planning beyond the government. Early involvement of the private sector, research institutions, and civil society brings technical expertise, encourages innovation, and helps build public support. The Latin America Water Funds Partnership—a collaboration among the Inter-American Development Bank, FEMSA Foundation, the Global Environment Facility, the International Climate Initiative, and The Nature Conservancy—has mobilized over $200 million to conserve watersheds and improve water security in the region. Similarly, in the United Kingdom, public-private pilot projects have tested biogas reuse and green infrastructure, while academic institutions have contributed vital research supporting national decarbonization strategies.

Regional alliances play an important role in fostering resilient infrastructure planning, particularly when ecosystems or climate risks extend across national borders. For instance, the Amazon Cooperation Treaty Organization (Organización del Tratado de Cooperación Amazónica, OTCA) brings together the eight Amazonian countries—Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname, and Venezuela—under the Amazon Cooperation Treaty. As the only socio-environmental bloc in Latin America, OTCA provides a platform for its members to coordinate policies, share technical knowledge, and undertake joint initiatives aimed at preserving the Amazon's environment and ensuring the sustainable use of its natural resources. By pooling expertise and aligning national strategies, such regional alliances strengthen collective capacity to address climate challenges that no single country could tackle alone.

Figure 3.2 illustrates how national, local, and sectoral instruments are interconnected within a broader planning framework. It highlights the connection between climate mitigation and adaptation mechanisms—such as Nationally Appropriate Mitigation Actions (NAMAs), Long-Term Low-Emission Development Strategies (LT-LEDS), National Adaptation Plans (NAPs), and National Adaptation Programmes of Action (NAPAs)—as part of countries' commitments under the UNFCCC, including Nationally Determined Contributions (NDCs) and Adaptation Communications (ADCOMs). These elements feed into national and local adaptation plans and strategies, which serve as the foundation for integrating climate considerations into infrastructure planning. Sectoral plans —covering water and sanitation, energy, and transport—are informed by these adaptation strategies, while local instruments such as land use planning, Sustainable Urban Mobility Plans (SUMPs) and Drinking Water and Sewer Master Plans enable the integration of resilience and adaptation measures at the local level and create shared responsibilities across governance levels. Integrated planning and alignment across instruments ensure that climate adaptation is mainstreamed into infrastructure development and land use policy (see Figure 3.2).

**Figure 3.2.**
National, Local, and Sectoral Adaptation Instruments in NAPs and NAPAs




**Note:** ADCOMs: Adaptation Communications; LT-LEDS: Long-Term Low-Emission Development Strategies; NAPs: National Adaptation Plans; NAMAs: Nationally Appropriate Mitigation Actions; NAPAs: National Adaptation Programmes of Action; NDCs: Nationally Determined Contributions.

**Source:** Authors' elaboration based on Calatayud et al. (2023).

Still, good planning requires supporting institutions that can accommodate changing or unpredictable circumstances. Rigid rules on financing, procurement, and project execution can delay critical interventions following disasters. Regulatory frameworks must be flexible enough to enable rapid emergency responses. For example, after Hurricane Sandy in 2013, the United States temporarily eased tax regulations to facilitate coordinated funding across federal, state, and local governments for infrastructure recovery (IEA, 2014).

Going forward, stronger planning institutions and alliances—within countries, across borders, and with nongovernmental actors—will be key to ensuring that infrastructure is resilient to nature's challenges. Ultimately, effective planning requires a balanced combination of institutional capabilities and investments tailored to sector-specific needs.

## A Policy Path to Resilient Infrastructure

Building infrastructure resilience requires more than shock-proofing physical assets. It calls for rethinking how infrastructure is planned, operated, maintained, and governed. While specific sectors face different challenges, several cross-cutting lessons apply across the infrastructure space.

Resilient infrastructure must be designed not just to withstand today's risks but also to adapt to tomorrow's uncertainty. Where and how infrastructure is built matters as much as what is built. Approaches grounded in diversification, decentralization, and redundancy reduce the likelihood of systemic failure during disruptions. Ensuring multiple transport routes, distributed water and energy systems, or localized service hubs can significantly improve continuity when shocks or natural disasters occur. NBS can deliver resilience dividends alongside environmental and social co-benefits. However, such strategies remain unevenly adopted across the region, and opportunities for scaling up are often missed. Ultimately, resilience relies not only on innovative design but also on commitment to maintenance and lifecycle investment. Chronic underinvestment, even in well-designed assets, puts infrastructure at risk of premature failure and erodes resilience gains. A forward-looking resilience agenda must therefore integrate lifecycle planning, sustained investment, and governance frameworks for both new and existing infrastructure.

Advancing infrastructure resilience in Latin America and the Caribbean requires combining price and non-price-based mechanisms on the supply- and demand-side of infrastructure services.

Price-based mechanisms include subsidies, tax incentives, and grants to encourage and stimulate investments. They also encompass tariff structures—such as increasing block rates, seasonal pricing, dynamic pricing, and targeted discounts—that shape consumption behavior. Insurance-premium adjustments and performance-based financing mechanisms can reward resilient infrastructure investments, while dedicated funds and contingency reserves—such as those for road adaptation and disaster response—support infrastructure services recovery following disasters. In addition, targeted financial tools such as grants for R&D, subsidies for underutilized technologies like desalination and rainwater harvesting, payment schemes for environmental services such as catchment protection and aquifer recharge, and tradable water certificates to improve resource allocation all support resilience.

Non-price-based mechanisms encompass a range of tools, from user-focused information campaigns, real-time alerts, efficiency labeling for appliances, and bill gamification to regulatory and planning actions such as updating design and construction standards, implementing land-use and zoning reforms, and establishing policy frameworks for nature-based solutions. Mandatory risk assessments, planning guidelines, and sectoral strategies help prioritize investments in critical and exposed assets. Public procurement reforms—such as resilience-focused technical specifications, risk-sharing clauses, and performance-based contracts—can also embed resilience into infrastructure delivery.

Strengthening resilience also requires capacity building and institutional support. Training for planners, public outreach, and programs that foster behavioral change are as important as investment in physical assets. Pilot projects for new materials and technologies, combined with maintenance upgrades, and the integration of green and grey infrastructure, can generate replicable models for scaling up.

Ultimately, embedding resilience into infrastructure systems is not just a technical challenge but a strategic priority. As development imperatives grow, the region must move decisively from reactive measures to proactive, integrated resilient infrastructure planning. This means mainstreaming resilience across all stages of infrastructure—from policy design and project preparation to implementation, and operations. It also requires empowering institutions with flexibility, resources, and reliable data to respond to evolving risks, while fostering collaboration across sectors and levels of government. And, importantly, it also requires securing funding and financing to scale up investments, which is the topic of the next chapter.

CHAPTER 4

# Two Pieces of the Puzzle: Funding and Financing Resilient Infrastructure

Given the urgent need to build resilient infrastructure systems in a world that is increasingly vulnerable to the vagaries of weather and extreme events, the question becomes, how to pay for these more adaptable systems? This chapter addresses that question. It focuses on how to mobilize the resources to upgrade infrastructure and explores the different—but often interconnected—concepts of funding and financing in the context of resilient infrastructure.

The concepts of "funding" and "financing" are frequently confused and mistakenly used interchangeably. Infrastructure investment refers to capital expenditure for the building, rehabilitation, and/or maintenance of infrastructure assets. Financing refers to pecuniary resources required to realize investments. Those resources can come from internal funds of the project developer or be borrowed from the market. In either case, the financing process creates an obligation for future repayment. Funding, in turn, determines how the financiers are paid back. It is the source of the money ultimately used to pay the investment. The funding sources for infrastructure projects can be the users of the services provided by the infrastructure—typically through fees or user charges—or from government transfers via the public budget. Public resources, in turn, can be secured through levies associated to varying degrees with the projects being funded, or from any other general source of government revenues. Thus, while funding and financing are certainly different, they are two pieces of the puzzle.

Multiple funding mechanisms are available for infrastructure projects depending on the project's characteristics. Importantly, clarifying the funding source of projects is what enables financing to materialize. This is particularly relevant in the case of resilient infrastructure. Resilient infrastructure differs from conventional infrastructure in that it is specifically designed to withstand, adapt to, and rapidly recover from shocks such as hurricanes, floods, storm surges, earthquakes, and other climate-related disasters.[21] Developing resilient infrastructure may require higher upfront investment than conventional infrastructure, for example in building redundancies to ensure systems and service continuity and, flexibility to adapt to changing and unexpected circumstances. The higher costs of building resilient infrastructure render long-term risk mitigation benefits that may be difficult to monetize, creating financing challenges that require innovative funding mechanisms and tailored financial instruments.

The chapter begins by clarifying the key concepts of funding and financing and then examines how these apply to resilient infrastructure. It then reviews the current landscape of infrastructure investment in the region, the role of public and private actors, and the instruments available to finance investments in resilient infrastructure. Finally, it discusses the barriers that limit investment and offers a roadmap for scaling up funding and financing for resilient infrastructure in Latin America and the Caribbean.

## A Primer for Funding and Financing Mechanisms for Infrastructure

Funding and financing are closely related but conceptually distinct elements of infrastructure investment. Understanding the difference between them is essential for designing effective investment strategies. Financing refers to the process of securing the upfront capital needed to build or upgrade infrastructure—whether through loans, bonds, or internal resources. Funding, by contrast, refers to the source of repayment for that capital over time.

The source of funding determines the nature of the risks that financiers face. When infrastructure is funded through user fees—such as tolls on a highway or tariffs on electricity— financiers must assess risks related to construction delays, which can postpone revenue collection; demand uncertainty, which may result in lower-than-expected usage; and regulatory changes, which can affect the pricing structure or the enforceability of contracts. For example, if a toll road is delayed or if fewer vehicles use

21 The concept falls under the broader umbrella of "sustainable infrastructure," which also includes projects that contribute to climate change mitigation, such as those that reduce greenhouse gas emissions.

it than projected, the revenue stream may be insufficient to repay the loan, increasing the risk for lenders. In such cases, the success of the project depends on its financial viability, and on the institutional strength, regulatory capacity, and credibility of the public sector (see Box 4.1 on the case of electricity storage in Chile).

In contrast, when a project is funded entirely by the government—such as a road built through public works—the risks shift. In this case, the key concerns for financiers are the government's ability to meet its payment obligations, the priority of those payments relative to other public expenditures, and the legal enforceability of any guarantees or contractual commitments. If the government faces fiscal stress or political changes, the reliability of payments may be compromised, even if the infrastructure itself is well used.

Mixed funding arrangements, in which both the public sector and private users pay a part, combine elements of both models. These arrangements introduce additional layers of complexity, including the government's capacity to design, implement, and monitor contracts effectively.

The funding structure also influences the types of financing instruments that can be used. For example, projects relying on public funding may require financing instruments that include guarantees from supranational entities, or so-called "seniority clauses" to mitigate risks associated with weak fiscal situations. Conversely, projects funded through user fees may benefit from lower financing costs if regulatory and contractual risks are well managed.

Brichetti, Cavallo, and Serebrisky (2024) classify funding mechanisms based on the relationship between those who benefit from infrastructure services and those who pay for them. When beneficiaries are clearly identifiable—such as drivers using a toll road or households connected to a water network—it is generally efficient to charge them directly. Transparent pricing systems that reflect the full cost of service provision, including operating expenses, capital costs, and a reasonable return for providers, guide users toward efficient consumption decisions. For instance, congestion pricing in urban transport can help manage demand and reduce overuse. However, in practice, full cost recovery through user fees is often constrained by factors such as low or unpredictable demand, affordability concerns, economies of scale, and the presence of positive externalities. These limitations are particularly relevant for basic services–

electricity, transport, and water and sanitation—in which pricing must balance financial sustainability with equitable access.

When direct cost recovery from users is not feasible, funding must come from indirect beneficiaries. A common example is the use of earmarked taxes—such as levies on fuel sales—to finance road infrastructure. While these mechanisms generate stable revenue streams for project financing, they weaken the link between service use and payment, potentially leading to inefficient usage patterns. For example, if fuel taxes are used to fund roads regardless of traffic volumes or congestion levels, the risk is that investments may not align with actual demand or economic returns.

Another widespread approach is to fund infrastructure with general government revenues. This method supports investments in services that are desirable even if not commercially viable. However, it also introduces challenges. Public budgets are often subject to political cycles, fiscal constraints, and competing priorities. These factors increase the volatility of funding and the risk of project delays or cancellations. And when service payments are completely dissociated from users, consumption decisions may become inefficient or wasteful. Moreover, in contexts with weak institutional capacity, public funding may be vulnerable to capture by interest groups. Despite these drawbacks, government funding remains a central pillar of infrastructure investment in the region, whether through direct public works or state-owned enterprises that deliver services on behalf of the state.[22]

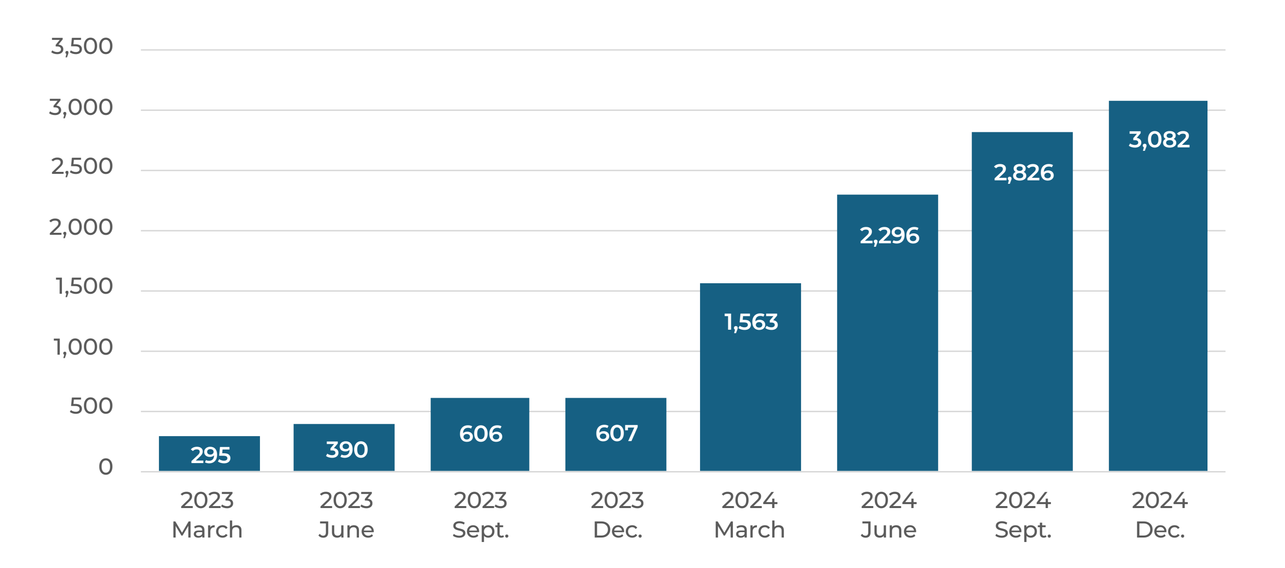
22 See, for example, Fay, Martimort and Straub (2021) for a model that rationalizes the fact that private finance is a minor share of infrastructure financing in developing countries.

## BOX 4.1. Regulation in Funding Infrastructure Investment: The Case of Electricity Storage in Chile

Energy Storage Systems (ESS) became essential for Chile's electricity grid as solar and wind power expanded rapidly across the country. The inherent intermittency of these renewable sources presented challenges for grid stability and supply reliability, making ESS capacity necessary. Beyond addressing intermittency issues, electrical storage is a valuable tool for system cost reduction by enabling generation shifting from low to peak demand periods, thereby avoiding substantial additional investments in transmission and distribution infrastructure.

Despite this clear need, and although significant price spreads existed between eventual ESS charging and discharging periods—potentially creating profitable arbitrage opportunities—storage developers lacked guarantees they could exploit them. This uncertainty came from the fact that under the Chilean regulatory framework—similar to most wholesale electricity markets in Latin America and the Caribbean—the System Operator (SO) had control over dispatch decisions instead of giving developers the possibility to freely arbitrage the opportunities. Moreover, unlike other regulatory frameworks that employ more sophisticated instruments, it remained unclear how their contribution to system stability and security would be remunerated. This uncertainty in future revenue streams made financing difficult for ESS developers, and hindered storage viability within the existing framework. Consequently, storage capacity expansion stagnated throughout 2023, growing at rates substantially below system requirements (see Figure B4.1.1).

**Figure B4.1.1.**
Energy Storage Capacity in Operation, Testing Stage, or Under Construction (MW)




**Source:** Authors' elaboration based on data from Comisión Nacional de Energía (CNE), Asociación Chilena de Energías Renovables y Almacenamiento (ACERA) and Asociación de Generadoras de Chile.

To incentivize the entry of ESS, a new regulation was enacted in late 2023 that incorporated a funding mechanism. Rather than relying solely on energy arbitrage, the regulation compensated storage projects based on their capacity to store electricity, explicitly recognizing their contribution to system stability and security. This approach provided storage developers with a certain revenue stream that directly offsets a portion of their capital investment, reducing dependency on uncertain energy price spreads. The impact of this regulatory intervention was immediate, with storage capacity expanding rapidly throughout 2024—demonstrating how mechanisms that secure future investment returns are essential for infrastructure development.

Whether this represents an optimal regulatory solution remains an open question. However, it constitutes a pragmatic approach within the constraints of the existing regulatory framework. Importantly, this regulation applies for ten years, providing both market certainty for ESS developers and sufficient time to develop a potentially more efficient long-term solution.

## Resilient versus Regular Infrastructure: Do Their Funding and Financing Differ?

Infrastructure projects, by their nature, are prone to several market failures that can lead to underinvestment. These include externalities, where the full social benefits of infrastructure extend beyond what private investors can capture; natural monopoly characteristics due to high fixed costs and network effects; and long investment horizons that may not align with private market preferences. These market failures are accentuated in the case of resilient infrastructure. The uncertainty surrounding, for example, climate risks amplify information asymmetries, making it harder for investors to assess risks and returns (see for example, Delgado et al., 2025; Marchau et al., 2019; and Fischbach et al., 2015). Additionally, the benefits of resilience—such as avoided damage from floods, hurricanes, or droughts—are inherently difficult to quantify and monetize because they represent prevented losses rather than direct revenue streams. This uncertainty, combined with potentially longer payback periods and more complex coordination requirements across multiple sectors and jurisdictions, compounds the traditional market failures that constrain infrastructure investment.

The consequences of these market failures are particularly severe in the context of climate resilience, where underinvestment can translate into catastrophic losses of life and property when extreme weather events strike unprepared communities. This underinvestment stems from the fact that many of the benefits of resilient infrastructure are not captured through direct payments by users. For example, a flood protection system may safeguard entire neighborhoods or cities, but it is difficult to charge each beneficiary in proportion to the protection they receive. These types of benefits, which extend beyond individual users to society at large, are known as positive externalities. Because the full value of the investment is not reflected in market transactions, private actors may lack the incentive to fund such projects, and governments may underinvest unless specific funding mechanisms are put in place.

The nature of resilience benefits and specifically, the uneven distribution of exposure and vulnerability, raises complex issues of fairness and funding responsibility. While some resilience investments, such as flood barriers or drainage systems, benefit specific geographic areas, others—like a more resilient water treatment plant—have broader spillover effects. For example, strengthening a water treatment facility against extreme weather may primarily protect nearby neighborhoods from service disruptions, but it also ensures continuity of supply for the network at large, benefiting users far beyond the immediate vicinity. This makes it difficult to define who should pay and how much. If funding policies were strictly aligned with the principle of "users pay," this would imply the need for granular, site-specific cost recovery mechanisms that reflect each user's exposure and benefit. However, practical and political limitations often prevent such precision, leading either to underinvestment in resilience or to inefficient public spending that does not adequately target the most vulnerable or exposed areas.

Traditionally, economists have proposed two main approaches to address the kinds of externalities that often lead to underinvestment in resilient infrastructure. The first, associated with Coase (1960), suggests that if property rights over risk exposure are clearly defined and transaction costs are low, private actors can negotiate solutions among themselves. For example, if a community is at risk of flooding, property owners might collectively invest in protective infrastructure or purchase insurance that reflects their exposure. This approach relies on market-based coordination, such as risk-based pricing in insurance markets, to internalize the costs of vulnerability. However, the Coasean approach presents significant practical limitations due to the difficulty of establishing clear property rights over complex risks and the high transaction costs of coordinating negotiations, especially among multiple parties.

The second approach, more commonly applied in practice, follows Pigou (1920), who advocated for the use of taxes and subsidies to correct market failures. Consider a village in a flood-prone area where some residents live directly along the riverbank while others are located further inland. When riverbank residents invest in protective measures like flood barriers or elevated foundations, these investments protect not only their own properties but also generate spillover benefits for the entire village. However, the directly exposed residents only consider their private benefits when making investment decisions, leading to underinvestment from a social perspective. A pigouvian subsidy would provide financial incentives to those most at risk to invest in flood protection at the socially optimal level. Additionally, if the subsidy is accompanied by a tax levied on all village residents, the funding for the protective infrastructure comes from those who benefit from it. In other words, the pigouvian subsidy prevents those who invest in protection from underinvesting, while taxes make those who benefit from protection pay for it. In any case, these instruments help align private incentives with broader social benefits by lowering the cost of resilience-enhancing investments or by generating public funds to finance them.

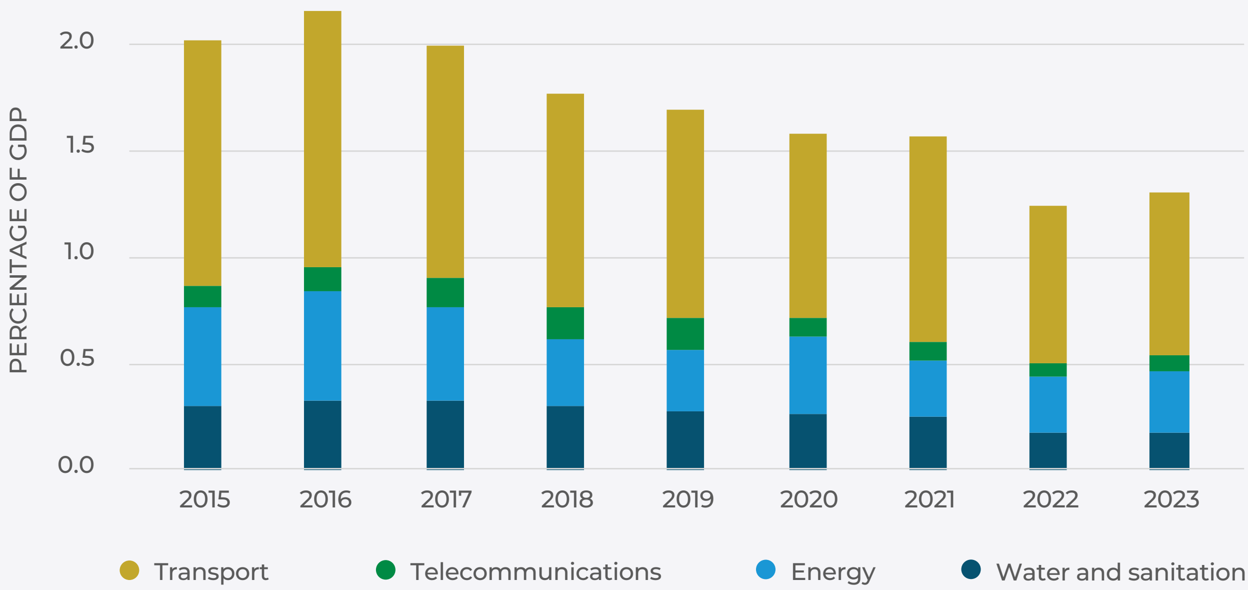
While both approaches offer tools to address externalities, they also raise important distributional questions. Who should bear the cost of resilience investments that benefit many but are paid for by a few? This issue becomes particularly salient when the benefits of infrastructure are diffuse or long-term, and the costs are immediate and concentrated. Resilient infrastructure projects typically involve additional costs at the time of investment—such as higher construction costs—while the benefits are realized over a longer-term horizon, often by population groups different from those initially incurring the expenses. Moreover, these benefits frequently take the form of avoided damage rather than immediate gains, making them less visible and harder to monetize. This temporal disconnection introduces significant political economy challenges, especially when public-sector funding decisions must be made by authorities who may not reap political rewards from the investments.

This intertemporal mismatch itself is a form of externality: those who pay today are not necessarily those who benefit tomorrow. Facilitating financing requires articulating funding policies that are tailored to the specific characteristics of each project. In addition, facilitating financing for resilient infrastructure requires financial instruments that help distribute costs and benefits more equitably over time. Examples include "green" or "climate bonds," which structure repayment schedules to spread financial burdens across current and future generations; or "climate resilience trust funds," which pool resources from public, private, or blended sources to support long-term investments.

## The State of Resilient Infrastructure Investment in the Region

Much of the investment in infrastructure in Latin America and the Caribbean is made by the public sector. Historically, the public sector has contributed between 60 percent and 80 percent of total investment in economic infrastructure (Cavallo, Powell, and Serebrisky, 2020). Figure 4.1 reports investment in infrastructure (fixed capital expenditure), based on an analysis of executed public budgets in Latin America and the Caribbean. Since 2015, countries have invested 1.7 percent of GDP, on average, with a declining trend since 2016. The actual investments have fallen short of what is needed, creating an infrastructure gap that is visible in the poor quality and quantity of infrastructure in the region (Brichetti et al., 2021). To close the infrastructure gap, countries in the region should invest up to 3.1 percent of their GDP—nearly twice the current level.

**Figure 4.1.**
Public Investment in Economic Infrastructure in Latin America and the Caribbean




**Source:** Authors' elaboration based on data from Infralatam: an IDB, CAF, and ECLAC initiative (2025).

How much of the actual investment was in resilient infrastructure? Unfortunately, there is no short answer. The problem begins with a lack of data compounded by the absence of accounting criteria defining an investment as "resilient."[23] To address these problems, Box 4.2 develops a proxy for resilient infrastructure investment based on information from the loan portfolios of Multilateral Development Banks (MDBs). MDB portfolios comprise a number of infrastructure projects—financed by these multilaterals—across some established categories, such as "climate finance." The analysis in Box 4.2 suggests that while total public investment in infrastructure has been declining in the region since 2015, the silver lining is that a growing share of that investment is allocated to resilient infrastructure.

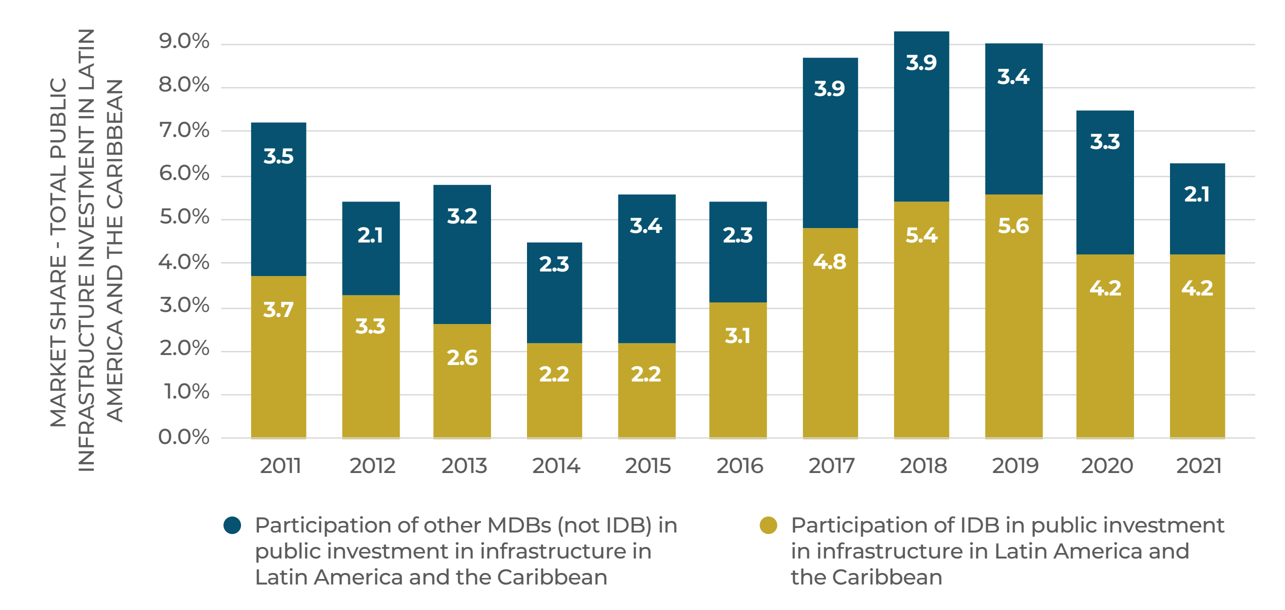
23 What makes an asset, like a road, be classified as resilient? See IDB and IDB Invest (2018).

## BOX 4.2. MDBs: A Case Study for Public Investment in Resilient Infrastructure

Member countries borrow from MDBs to finance infrastructure investments.[24] Figure B4.2.1 compiles publicly available information on the contribution of major development banks to infrastructure investment in Latin America and the Caribbean through their sovereign-guaranteed and nonsovereign guaranteed windows.

**Figure B4.2.1.**

MDB Participation in Public Infrastructure Investment, 2011–2021: Market Share




**Source:** Authors' elaboration based on data from IDB and IDB invest internal data and other MDB public data from their websites (only available until 2021).

**Note:** MDB: Multilateral Development Banks; IDB: Inter-American Development Bank. It includes both sovereign and nonsovereign guaranteed loans.

24 For a detailed comparison of lending instruments see https://www.iadb.org/en/how-we-can-work-together/public-sector/financing-offerings/instrument-comparison?list=LBR,IRF,ESP

Over the past decade, MDBs accounted for approximately 7 percent of total public infrastructure investment in Latin America and the Caribbean, on average. That is, more than one of every 20 infrastructure projects are developed in collaboration with an MDB.

The Joint Report on MDB Climate Finance (2024) tracks finance using standardized principles and agreed-upon methodologies to monitor so-called "climate adaptation" and "mitigation financing." Mitigation financing focuses on projects aimed at reducing greenhouse gas emissions; adaptation financing aims to reduce the risks and vulnerabilities associated with climate change on infrastructure and is, therefore, closely related to the concept of resilient infrastructure. To qualify a project fully or partially as MDB adaptation finance, it must undergo a three-step process:

1. Identify the project's context in relation to vulnerabilities posed by climate change.

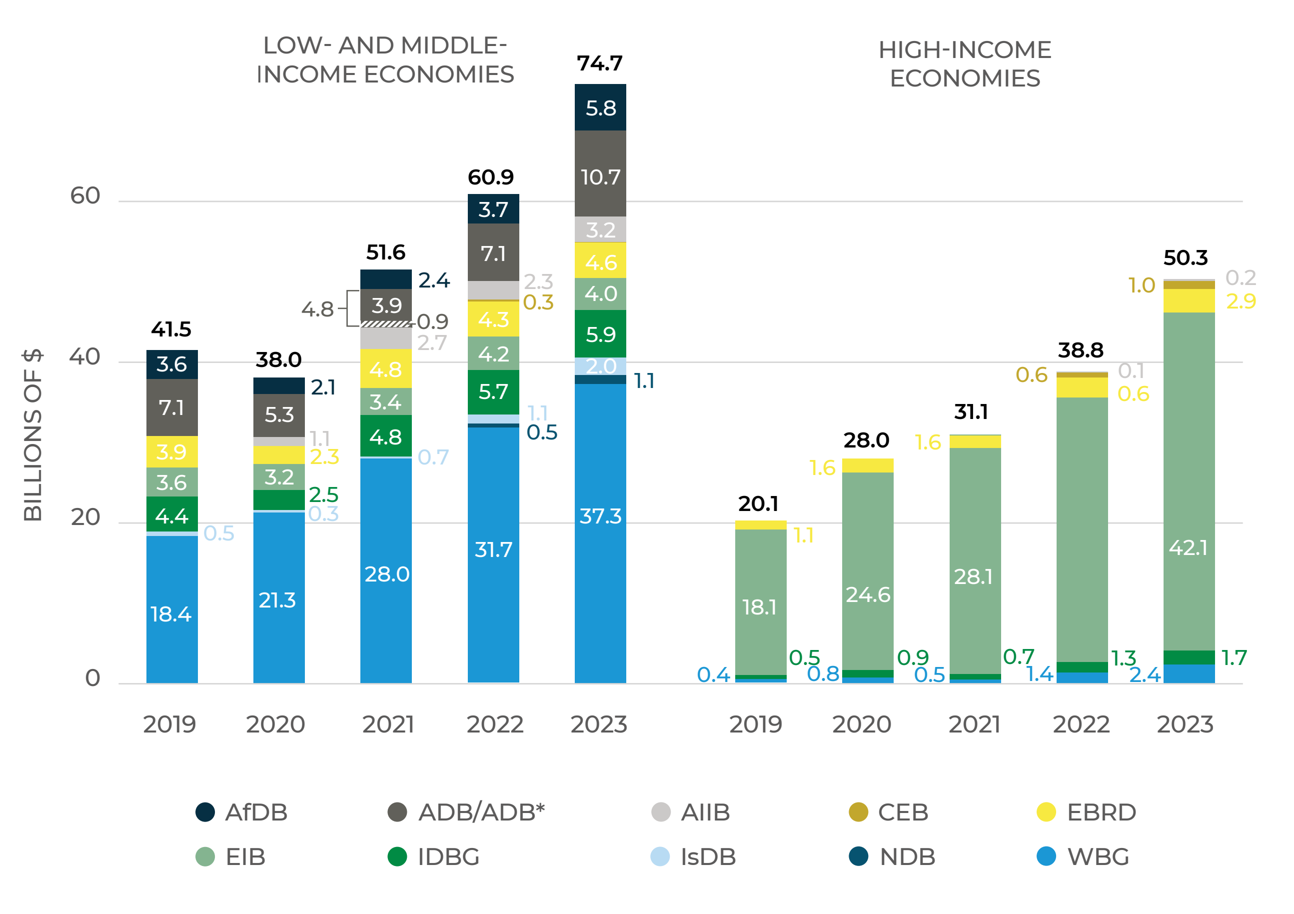
2. Make an explicit statement of intent to address these vulnerabilities as part of the project.

3. Establish a clear and direct connection between the identified vulnerabilities and the specific activities of the project.

Figure B4.2.2 shows that climate-related finance commitments from MDBs have steadily increased over the years, particularly for low- and middle-income economies. In 2023, these commitments reached $74.7 billion (up from $23.8 billion in 2013), compared to $50 billion for high-income economies. The World Bank Group leads with almost $40 billion, followed by the Asian Development Bank, which has provided $10.7 billion. The IDB contributed $5.9 billion to low- and middle-income economies, and $1.7 billion to high-income economies.

**Figure B4.2.2.**

Climate Finance Commitments by Multilateral Development Banks




**Source:** European Investment Bank et al. (2024).

**Note:** AfDB: African Development Bank; ADB: Asian Development Bank; AIIB: Asian Infrastructure Investment Bank; CEB: Council of Europe Development Bank; EBRD: European Bank for Reconstruction and Development; EIB: European Investment Bank; IDBG: Inter-American Development Bank Group; IsDB: Islamic Development Bank; NDB: New Development Bank; WB: World Bank.

MDBs common methodology considers the following activities for adaptation finance.[25]

25 For more details, see African Development Bank et al. (2022).

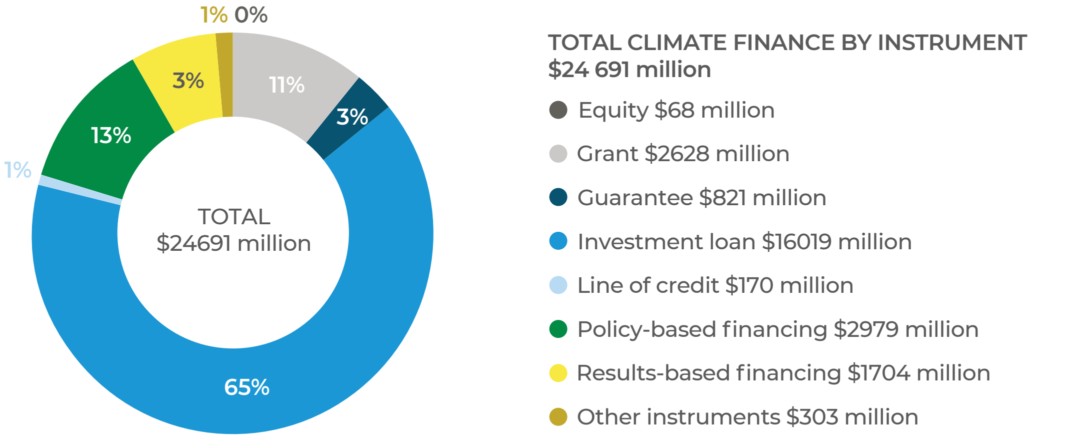
1. **Activities that are adapted:** These activities manage physical climate risks to ensure that project objectives are met despite these challenges. They involve necessary adjustments for effective performance against climate change impacts, but adaptation is not their primary goal. For example, a coastal highway in Belize was elevated and reinforced to withstand increased flooding and storm surges due to rising sea levels. While the primary goal of the project was to improve transportation connectivity, design adjustments were made to ensure the road remains operational under future climate conditions.

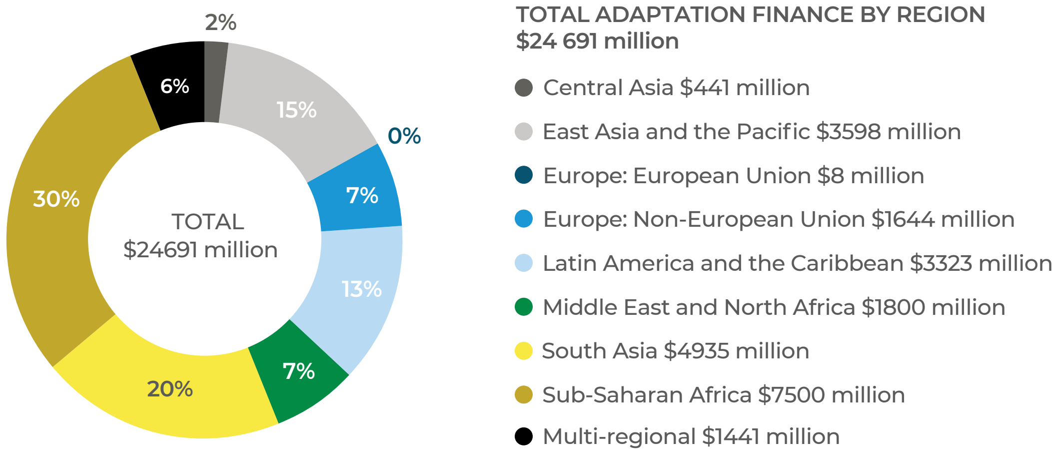
2. **Activities that share objectives of adaptation and development:** These activities reduce climate risks while enhancing the adaptive capacity of the system involved. They are based on an understanding of relevant climate risks and include adjustments for both current and anticipated impacts, with adaptation as a key objective. An example is a rural water supply project in Honduras that aims to both expand access to clean water and install drought-resilient infrastructure (e.g., rainwater harvesting systems and aquifer recharge zones).

3. **Activities that enable adaptation**: These activities address the root causes of vulnerability to climate change and remove barriers to adaptation. They help create supportive conditions for policy and regulatory development, capacity building, and technological advancement, with adaptation as the primary focus. For example, a regional climate information system in the Andean countries provides early warning data, climate modeling, and capacity-building for local governments to integrate climate risks into planning.

In 2023, focusing on low- and middle-income economies, adaptation finance represented 33 percent of total climate finance provided by MDBs ($24,691 million). These funds have primarily been distributed through investment loans (65 percent) and to a lesser extent through policy-based loans (13 percent) and grants (11 percent). Approximately 13 percent of total adaptation finance goes to Latin America and the Caribbean (Figure B4.2.3).

**Figure B4.2.3.**
MDB Adaptation Finance by Region in Low- and Middle-Income Economies, 2023



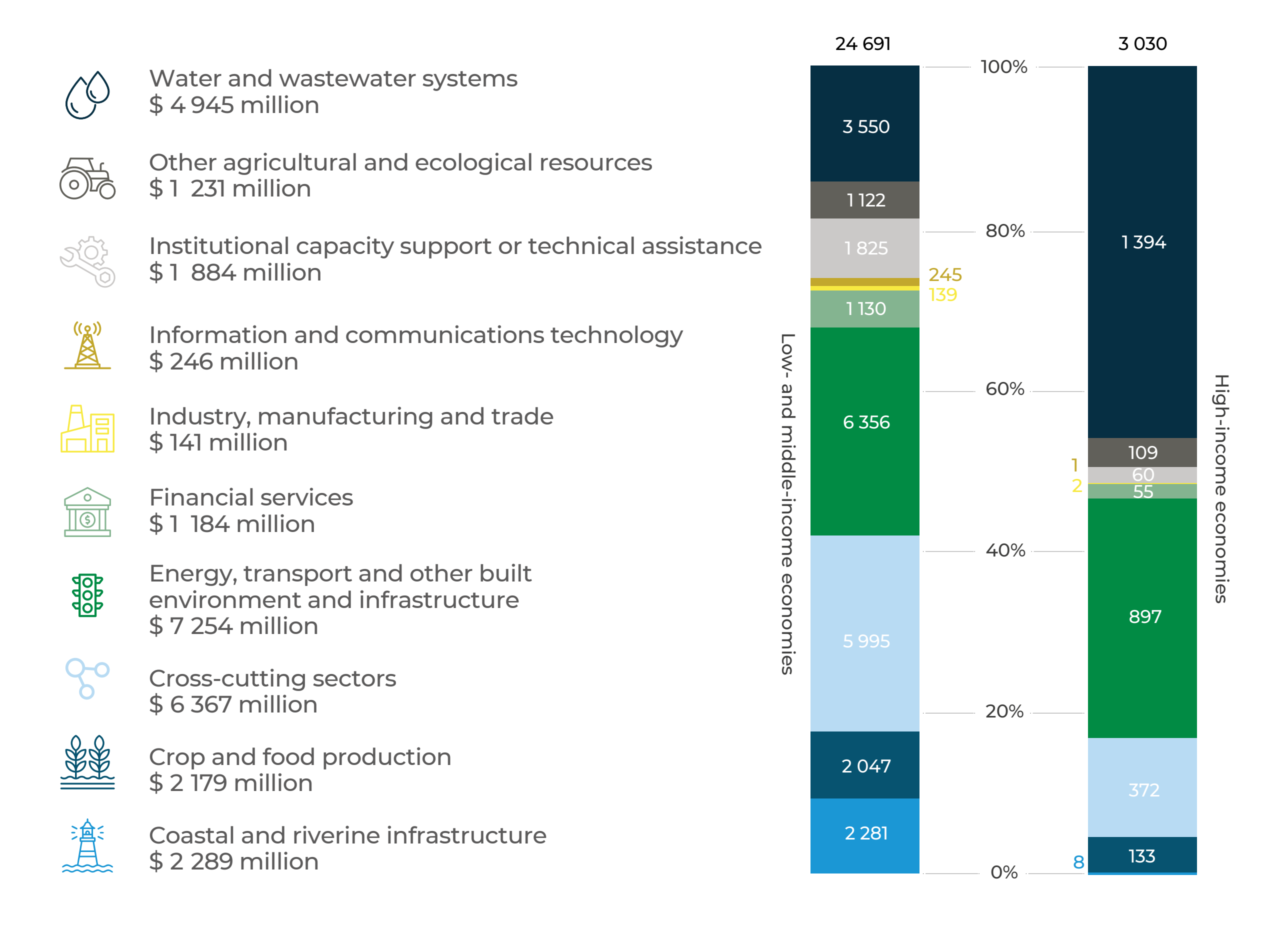




**Source:** African Development Bank et al. (2024).

The "Common Principles for Climate Mitigation Finance Tracking" (African Development Bank et al., 2023) provides a comprehensive list of eligible activities categorized by sector. The sectors included are: energy; mining and metal production; manufacturing; agriculture, forestry, land use, and fisheries; water supply and wastewater management; solid waste management; transport; buildings, public facilities, and end-use energy efficiency; information and communication technology (ICT) and digital technologies; research, development, and innovation; as well as cross-sectoral activities.

In 2023, the sectors that received most climate finance for adaptation in low- and middle-income countries were energy; transport and other built environment infrastructure (25 percent); and water and wastewater systems (14 percent). This was followed by coastal and riverine infrastructure (9 percent) and crop and food production (8.2 percent) (see Figure B4.2.4).

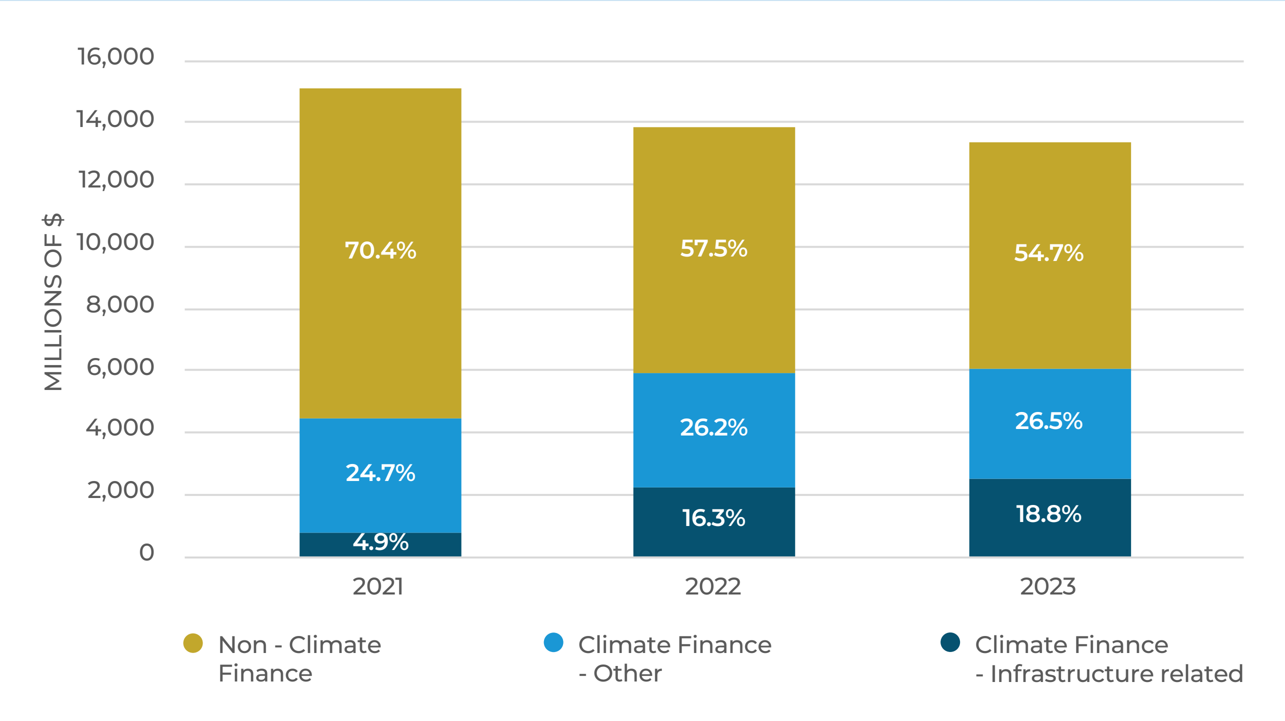
**Figure B4.2.4.**
Adaptation Finance by Sector




**Source:** European Investment Bank et al. (2024).

Infrastructure sectors directly account for one of every two dollars committed by Multilateral Development Banks in low- and middle-income economies. This figure is even higher when considering cross-cutting issues in which infrastructure plays a vital role. As a result, a significant portion of adaptation finance from MDBs is directed toward projects that focus on resilient infrastructure.

**Figure B4.2.5.**
Inter-American Development Bank Climate Finance (2021-2023), Infrastructure-related



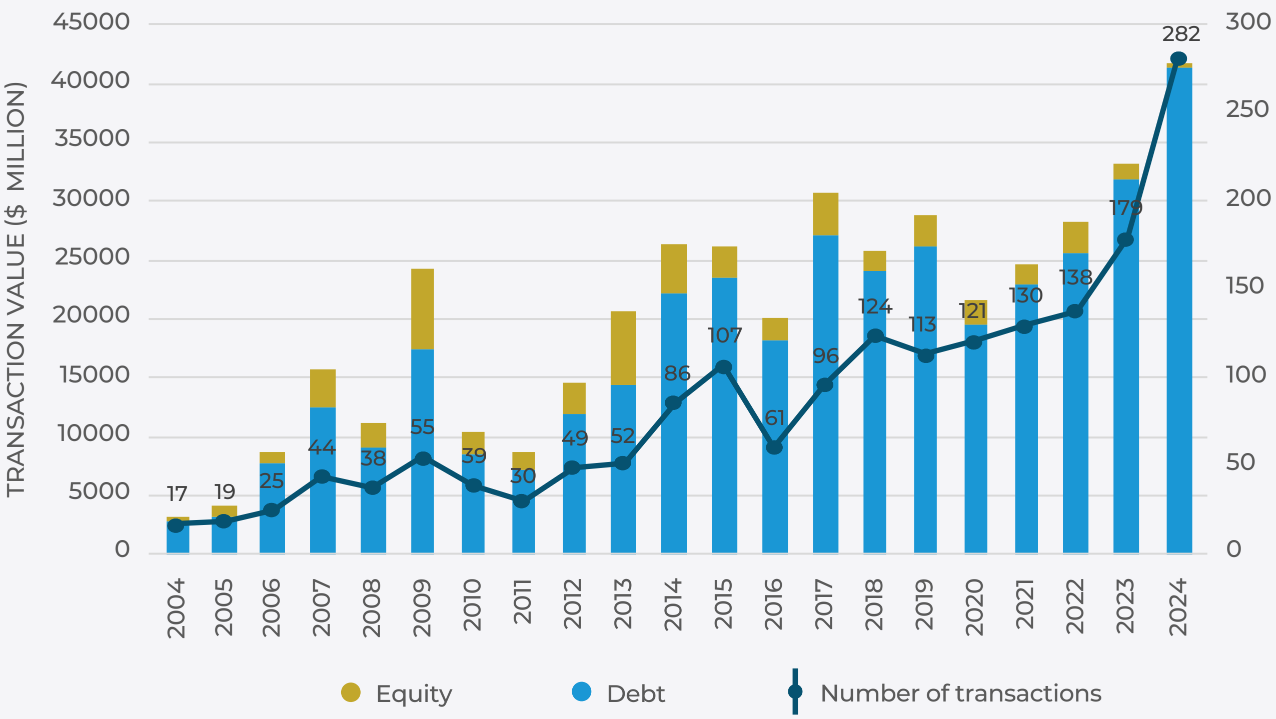

**Source:** Authors' elaboration based on data from MDB climate finance database.

In the case of the Inter-American Development Bank Group, in 2023, climate finance accounted for nearly half of total financing (see Figure B4.2.5). Of this amount, infrastructure-related climate finance represented 40 percent, a share that has been increasing over time, implying that financing for investment in resilient infrastructure is rising.

Despite the growing share of investment in resilient infrastructure, the overall investment is not enough to close existing gaps. And satisfying the need for increased investment is beyond what the public sectors in the region can afford by themselves (see Cavallo, Powell, and Serebrisky, 2020). Consequently, governments across the region have sought to attract private participation in infrastructure investment. In other words, interest is growing in attracting private investment to increase investment in infrastructure.

**Figure 4.2.**

Private Investment in Public Infrastructure




**Source:** Authors' elaboration based on data from IJGlobal dataset (2025).

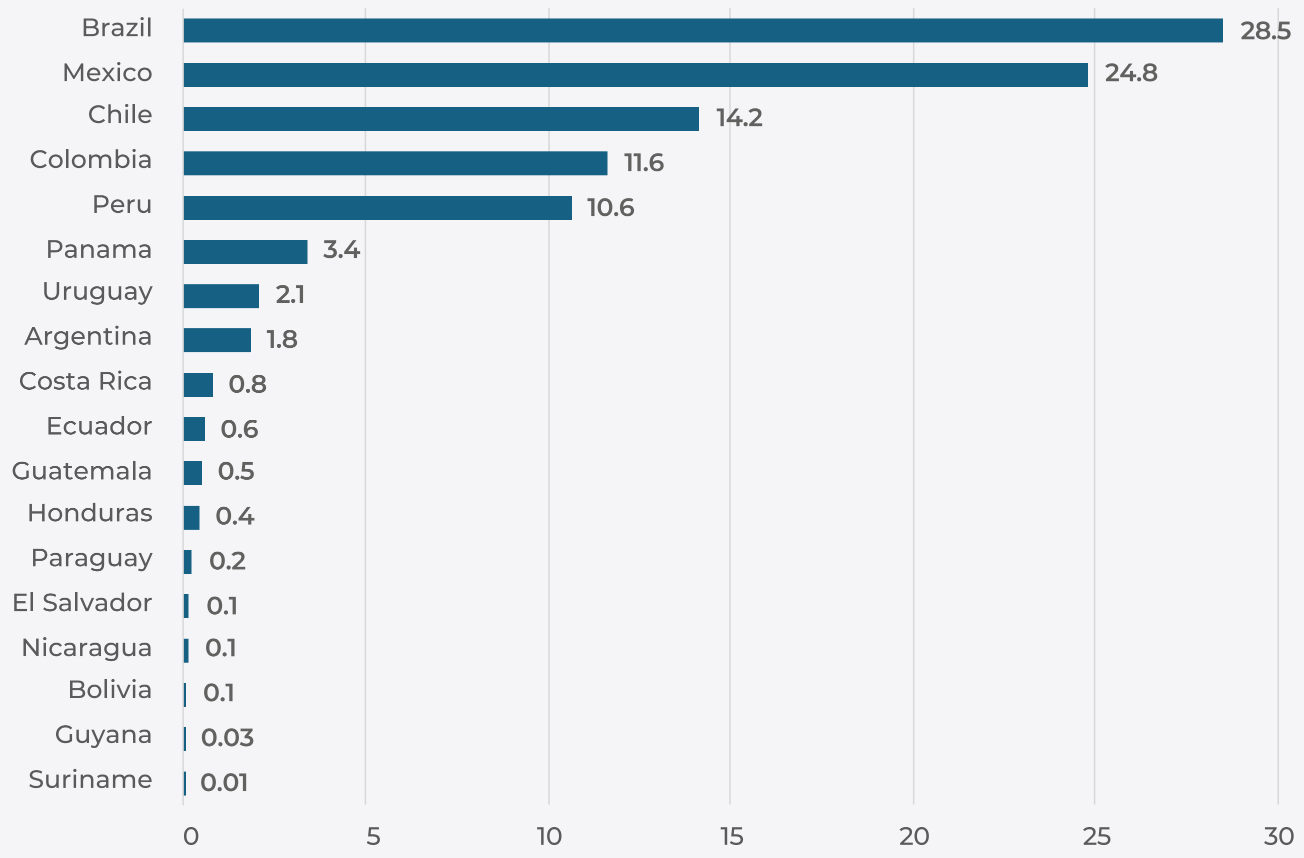
**Note:** The plot shows the total private investment at the year of financial closing, which may differ from the moment when funds are disbursed, or the project is executed.

The private sector plays a significant role in infrastructure investment in Latin America and the Caribbean. In fact, the region leads the world in private participation in public infrastructure financing, with nearly $800 billion invested since 1990 (World Bank, 2025). When compared to other regions, private participation in infrastructure is 25 percent higher than in East Asia and the Pacific economies, and almost 10 times greater than in Sub-Saharan Africa during the same period. However, relative to GDP, this investment accounts for only approximately 0.6 percent of the regional GDP,[26] whereas, as previously mentioned, public investment is 1.7 percent of GDP.

Still, while low in levels, private investment in infrastructure has trended upwards since the early 2000s (see Figure 4.2). Since then, the market has grown and diversified into new sectors and countries that improved their enabling environment for attracting private participation into infrastructure investment. Notably, during this period, the total number of public projects with private participation in sectors such as transport, energy, water, sanitation, and telecommunications has increased sixfold.

26 Various sources track private participation in infrastructure investment; the World Bank's Private Participation Initiative Database and IJGlobal are the most common. These databases differ in specifications and coverage but record investments based on the financial close year. Understanding actual yearly private sector investment is complex due to contract specifics. For instance, 0.6 percent of the Regional GDP accounts for all capital expenditure from projects that reached financial close from 1990 to 2025, even if some investments occur later. For more information, see https://ppi.worldbank.org/en/ppi.

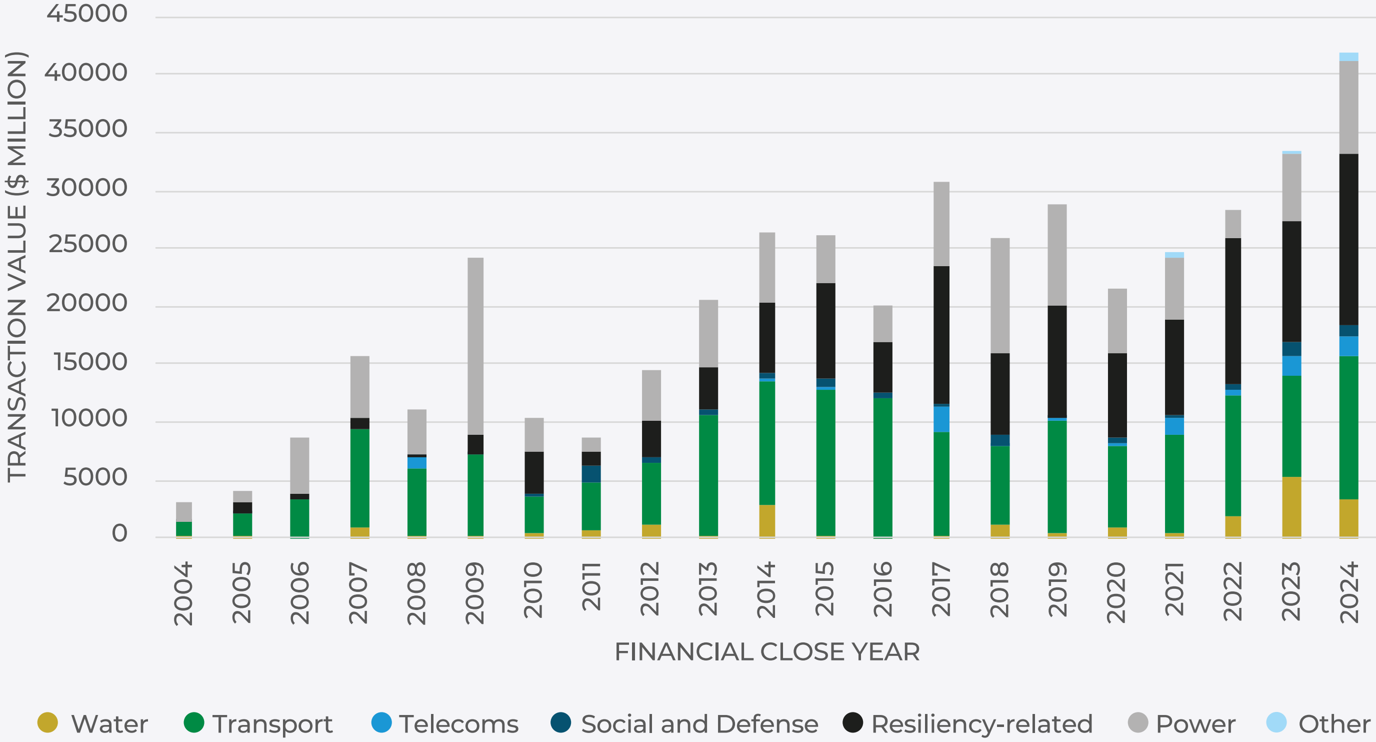
**Figure 4.3.**
Private Investment in Public Infrastructure by Country
(percentage of total)




**Source:** Authors' elaboration based on data from IJGlobal dataset (2025).

While on the rise in aggregate figures, private investment in infrastructure has been concentrated in a few countries, with Brazil (28.5 Percent), Mexico (24.8 percent), Chile (14.2 percent), Colombia (11.6 percent), and Peru (10.6 percent) accounting for nearly 90 percent of the total (see Figure 4.3). However, other countries are slowly entering the picture (see Alvarez Pagliuca et al., 2022). Notable developments include Panama, which increased its share from 2.8 percent in 2022 to 3.4 percent in 2025, and Ecuador, which now accounts for 0.6 percent of total private investment in the region. Additionally, investment is distributed across a larger variety of sectors, with projects in water, sanitation, and social infrastructure representing close to 9 percent of total private investment in infrastructure (see Figure 4.4).

**Figure 4.4.**
Private Investment in Public Infrastructure by Sector




**Source:** Authors' elaboration based on data from IJGlobal dataset (2025).

**Note:** The figure shows total private investment at the year of financial closing, which may differ from the moment when funds are disbursed, or the project is executed.

How much of these investments can be linked to resilient infrastructure? Following a similar taxonomy to the climate finance literature (see Box 4.2), projects can be split into those that are "inherently resilient," as they contribute to the overall improvement of sector resilience, and "traditional" projects that are adapting—such as retrofitting an existing structure. Additionally, some projects include specific components aimed at enhancing the resilience of infrastructure services. An analysis of a dataset of around 2,600 infrastructure project transactions in Latin America and the Caribbean identified all projects that specifically mention "resilience" in their scope,[27] as well as those that aim to improve the resilience of their

27 All references to resiliency, sustainability, climate change, adaptation, and green infrastructure have been reviewed in the project titles and descriptions of the IJGlobal database from 2004 to the present.

respective sectors—for example, renewable energy initiatives that diversify the electricity generation matrices of countries. This analysis is a proxy for how much the private sector is investing in resilience-related infrastructure. Figure 4.4 shows that the total private investment in resilient infrastructure has increased from $2,889 million between 2004-2008 to $53,507 million between 2020-2024. This implies that the percentage of resiliency-related infrastructure projects has increased from 2.1 percent in 2004 to 35 percent of total private investment in infrastructure in 2024.

The bottom line is that within a general context of low public and private investment in infrastructure, investment in resilient infrastructure is gaining ground. The challenge for the region is to scale up investments to close the existing gaps. That will require using and expanding the toolbox for resilient infrastructure financing.

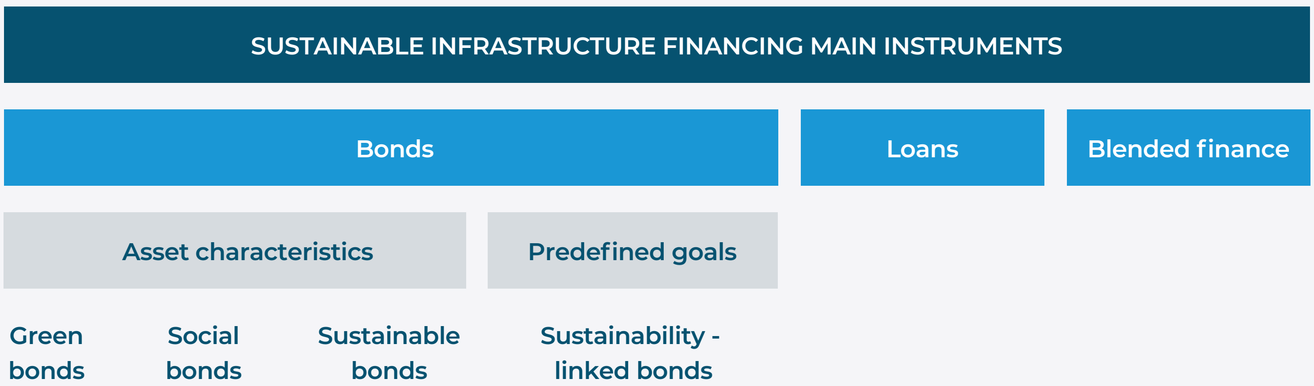
## A Toolbox for Resilient Infrastructure Financing

Financing for resilient infrastructure investment is within the scope of "sustainable finance," namely, the resources from different sources aimed at supporting investments that generate positive social and/or environmental outcomes.[28] Traditionally, this concept has encompassed "green" and/or "socially responsible" projects. The main instruments for sustainable finance are bonds, all types of loans, and blended (public and private) finance (Figure 4.5).

28 This subsection builds from Arciniegas et al. (forthcoming).

**Figure 4.5.**

A Conceptual Framework for Resilient Infrastructure Financing Instruments




**Source:** Authors' elaboration.

Sustainable loans encompass all types of loan instruments and contingent financing facilities, including lines of credit, guarantee slips, and letters of credit, designed to incentivize borrowers to achieve sustainability objectives.[29] Blended finance refers to the strategic use of concessional financing[30] in projects for which actual or perceived risks are too high for commercial finance alone (IDB Invest, 2025). This approach relies on the complementary use of grants, concessional instruments, and reimbursable financing from public and private sources to enhance the viability

29 In line with ICMA's Sustainability-Linked Lending Principles (SLLP), borrower performance is assessed using sustainability performance objectives (SPTs), which include key performance indicators (KPIs). By tying loan terms to sustainability outcomes, borrowers are encouraged to enhance their sustainability profile throughout the duration of the loan. Instead of dictating how the funds must be used, these loans aim to improve the borrower's sustainability profile by aligning loan conditions with their performance against the established SPTs. Examples of sustainable lending include loans designed to enhance the energy efficiency ratings of buildings and machinery owned or leased by the borrower, as well as loans that promote water conservation initiatives undertaken by the borrower, among other possibilities. For a more detailed discussion, please refer to Arciniegas et al. (forthcoming).

30 Concessional financing refers to financial mechanisms or instruments that offer more favorable terms and conditions than those typically available in the market, such as lower interest rates compared to commercial rates. It does not represent a single type of financing but encompasses a variety of mechanisms and products that provide benefits, including lower interest rates, extended repayment periods, and flexible payment structures. These terms are often not acceptable to commercial financial institutions. By making financing more accessible, concessional financing helps reduce the perceived risks of a project, making it more attractive to commercial lenders. Arciniegas et al. (forthcoming).

and financial sustainability of projects that contribute to sustainable development.[31]

Sustainable infrastructure bonds are financial instruments whose net proceeds finance, or refinance, exclusively eligible infrastructure projects—which in turn are categorized as green, social, or sustainable bonds. Sustainable-linked bonds are instruments whose characteristics depend on whether the borrower, or the issuer, meets predefined objectives and goals linked to key performance indicators. Box 4.3 provides a taxonomy of the different types of sustainable bonds.

**BOX 4.3.**

## Learning the Language of Sustainable Bonds

### Green Infrastructure Bonds

Green bonds are widely recognized as one of the primary financing instruments used to advance the Sustainable Development Goals (SDGs) and utilized for eligible projects that provide significant environmental benefits. These benefits will be evaluated and, where possible, quantified by the issuer.

The Green Bond Principles (GBP) outline several general categories of projects that qualify for green bond financing, focusing on environmental objectives. These categories include climate change mitigation, climate change adaptation, conservation of natural resources, biodiversity conservation, and pollution control and prevention.[32] Additionally, according to the International Capital Market

31 https://worldbank.org/en/news/feature/2021/09/16/what-you-need-to-know-about-concessional-finance-for-climate-action
https://idbinvest.org/es/publicaciones/instituciones-de-desarrollo-financiero-confeccionan-reporte-sobre-la-financiacion
https://www.caf.com/media/3382110/drfi-financiamiento-mixto.pdf

32 https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/Translations/2021/Spanish-GBP-2021.pdf?vid=2.

Association (ICMA), Blue Bonds are also categorized as green bonds because they emphasize the sustainable use of maritime resources, provided they align with the key principles of the GBP.

Annex 4.1 presents an indicative list of project categories featuring the types of projects most commonly supported by the green bond market. Projects may align with multiple environmental categories or objectives. The definition of what qualifies as a green project varies based on sector and geography. Various taxonomies, nomenclatures, and initiatives at both global and national levels provide further guidance to green bond issuers regarding what investors consider green and eligible. In Latin America and the Caribbean, these taxonomies are at different stages of development.

## Social Infrastructure Bonds

Social bonds, similar in structure to green bonds, aim to directly address and alleviate specific social issues while promoting positive social outcomes, particularly for targeted populations. A social problem is one that threatens or damages the well-being of society or a specific group. Examples of target populations include but are not limited to: individuals living below the poverty line, marginalized communities, people with disabilities, migrants and displaced individuals, those with low levels of education, the unemployed, women and sexual or gender minorities, aging populations, and vulnerable youth. The International Capital Market Association (ICMA) acknowledges that the definition of target populations varies depending on the local context. In some cases, addressing the needs of the general public may also serve these specific populations.[33]

According to Social Bond Principles (SBP), the key aspect of a social bond is the allocation of bond funds to eligible social projects that deliver clear social benefits. These benefits will be evaluated and, when possible, quantified by the issuer. Annex 4.2 provides an indicative list of project categories, highlighting the types of projects that the social bond market typically supports.[34]

33 https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/Translations/2021/Spanish-SBP-2021.pdf?vid=2.

34 https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/Translations/2021/Spanish-SBP-2021.pdf?vid=2.

Recently, overall sustainable (green plus social) bonds have emerged as a new category of financial instruments. These bonds are specifically designed so that the net proceeds are used exclusively to finance or refinance eligible projects, either partially or fully, encompassing both green projects and social projects that provide environmental and social benefits. The issuer of these bonds must classify how the funds will be used based on the primary objectives of the projects. Similar to green and social bonds, the key aspect of sustainable bonds is that the proceeds are allocated to eligible projects.

## Sustainability-linked Infrastructure Bonds

Sustainability-linked bonds are a type of bond for which the financial and/or structural characteristics change based on whether the issuer meets specific, predetermined sustainability (ESG) objectives. Issuers clearly commit to improving their sustainability performance within a defined timeframe, which is documented in the bond agreement. As a result, sustainability-linked bonds are based on projected performance.

The sustainability goals are assessed using key performance indicators (KPIs) and evaluated against sustainability performance targets (SPTs). Unlike sustainable bonds, which require the disclosure of how the funds will be used, the funds raised from sustainability-linked bonds can be utilized for general corporate purposes. Therefore, the specific use of the funds does not influence their classification.[35] The Principles of Sustainability-Linked Bonds (SLBP) recommend that issuers clearly communicate the rationale behind their selection of Key Performance Indicators (KPIs), the reasons for their Sustainability Performance Targets (SPTs), any potential changes to the financial and/or structural characteristics of the bond, and the factors that may lead to these variations. Additionally, issuers should commit to post-issuance reporting and independent verification, as well as provide an overview of their alignment with the SLBPs.[36]

35 https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/Translations/2020/Spanish-SLBP2020-06-280920.pdf

36 https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/Translations/2020/Spanish-SLBP2020-06-280920.pdf

## The Evolution of Sustainable Bonds in Latin America and the Caribbean

Sustainable bonds exhibit significant heterogeneity in terms of their end uses, issuer types, and issuance amounts. As a result, bond issuance structures vary widely across countries. One of the more attractive features of these bonds is the assurance they provide investors that their capital will fund specific initiatives. This section presents the evolution of sustainable bond adoption in the region as a financing method, along with descriptive statistics showing the diversity in the regional landscape.

Figure 4.6 illustrates the growth of green, social, sustainability, and sustainability-linked (GSS+) bonds in Latin America and the Caribbean from 2014 to 2022. The left axis shows the volume of different types of sustainable bonds, while the right axis shows the GSS+ international bonds as a percentage of total international bond issuance.[37] GSS+ bond issuance has increased, particularly after 2019.

Also, the line that tracks the percentage of international GSS+ bonds relative to total international bond issuance shows an upward trend. This indicates that GSS+ bonds continued to gain market share in the overall bond market, reaching approximately 40 percent by 2022—a remarkable transformation from near-zero between 2014 and 2018.[38]

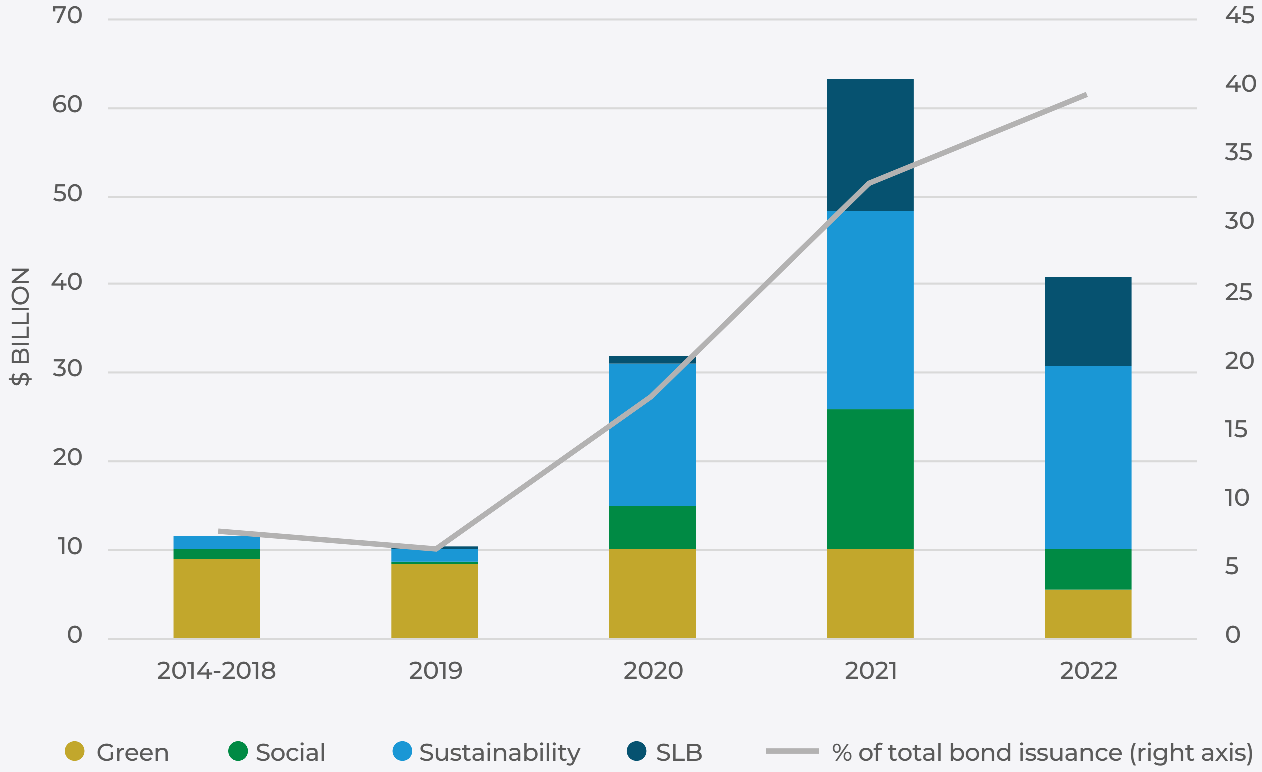
The composition of GSS+ bonds has also evolved. Green bonds dominated initially but were gradually supplemented by social bonds, sustainability bonds, and sustainability-linked bonds (SLBs) (see Figure 4.6).

37 Instead of using the ratio between total GSS+ bonds and total bonds issued, the same ratio was calculated but for bonds issued in international currency. While in this work, thanks to information available at the Climate Bond Initiative, there is information on the total GSS+ bonds issued by country, there is no information regarding total bonds (in local and international currency) issued in Latin America and the Caribbean.

38 Nevertheless, this trend does not necessarily indicate that sustainable investment was previously absent. This is because the formal labeling of GSS+ bonds marked a turning point in how these investments are identified and tracked, meaning that many investments that could have been GSS+ in substance were simply not categorized as such before.

**Figure 4.6.**

Total Amount (in billions of US$) of GSS+ Bonds in Latin America and the Caribbean by Types and Years

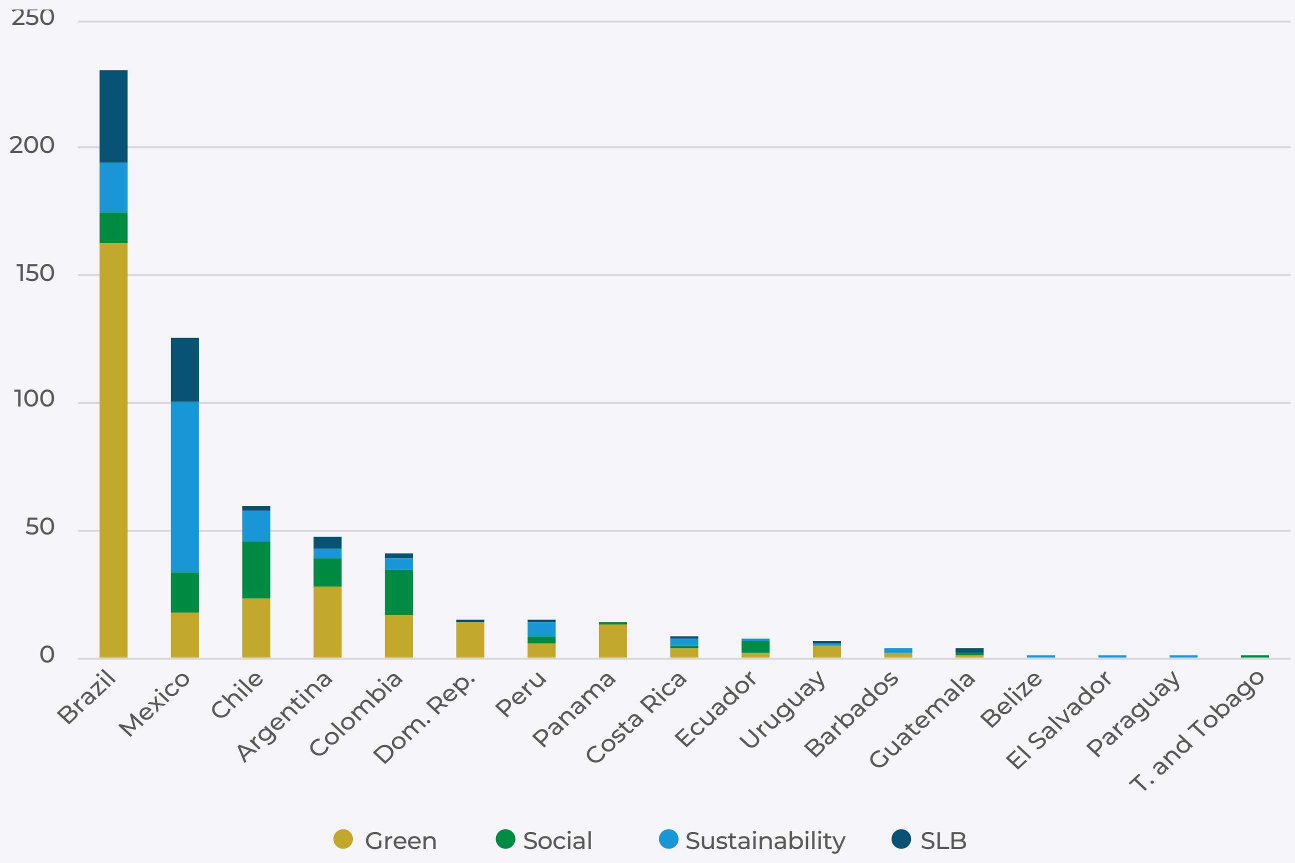



**Source:** Authors' elaboration based on Dagnino Contreras et al. (2023) and Velloso and Perrotti (2023).

**Note:** SLB: Sustainability-linked bond.

In terms of the numbers of bonds by country, Brazil leads with approximately 230 GSS+ bonds issued, led strongly by green bonds followed by sustainability-linked ones (see Figure 4.7). Mexico follows with around 125 bonds, displaying a clear majority of sustainability bonds and a balanced distribution across green, social, and sustainability-linked bonds. The figure also shows a clear hierarchy among the larger economies (Brazil, Mexico, Chile, Argentina, Colombia), which have issued significantly more bonds than smaller economies. Green bonds are the most common type of sustainable finance instrument across nearly all countries, aligning with their early adoption in the region.

**Figure 4.7.**
Number of GSS+ Bonds Issued in the Region by Country and Type (2014-2022)



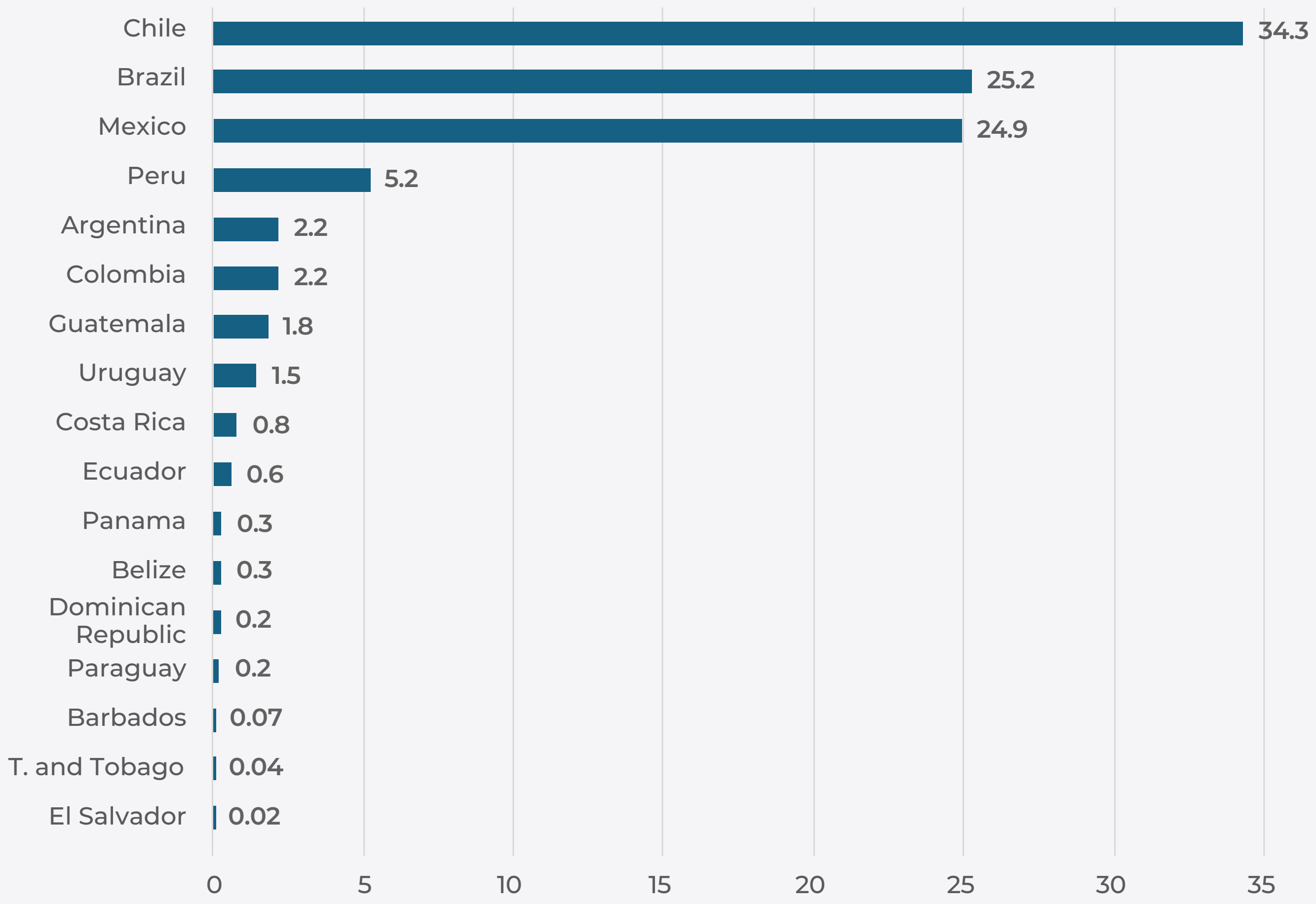

**Source:** Authors' elaboration based on Dagnino Contreras et al. (2023).

**Note:** SLB: Sustainability-linked bond.

In terms of the US$ value of issuances, the GSS+ bonds issued in Latin America and the Caribbean between 2014 and 2022 reached a total amount of $125.5 billion, excluding supranational bonds. Figure 4.8 shows the distribution by country. Chile leads with 34.3 percent of the total amount (approximately $43.0 billion), followed by Brazil at 25.2 percent ($31.6 billion), Mexico at 24.9 percent ($31.3 billion), and Peru at 5.2 percent ($6.5 billion). Other countries with smaller shares include Argentina and Colombia (both at 2.2 percent, or about $2.8 billion each), Guatemala (1.8 percent, approximately $2.3 billion), and Uruguay (1.5 percent, around $1.9 billion).

**Figure 4.8.**

Share of GSS+ Bonds Issued in the Region by Country, 2014-2022 (percentage of total)




**Source:** Author's elaboration based on Dagnino Contreras et al. (2023).

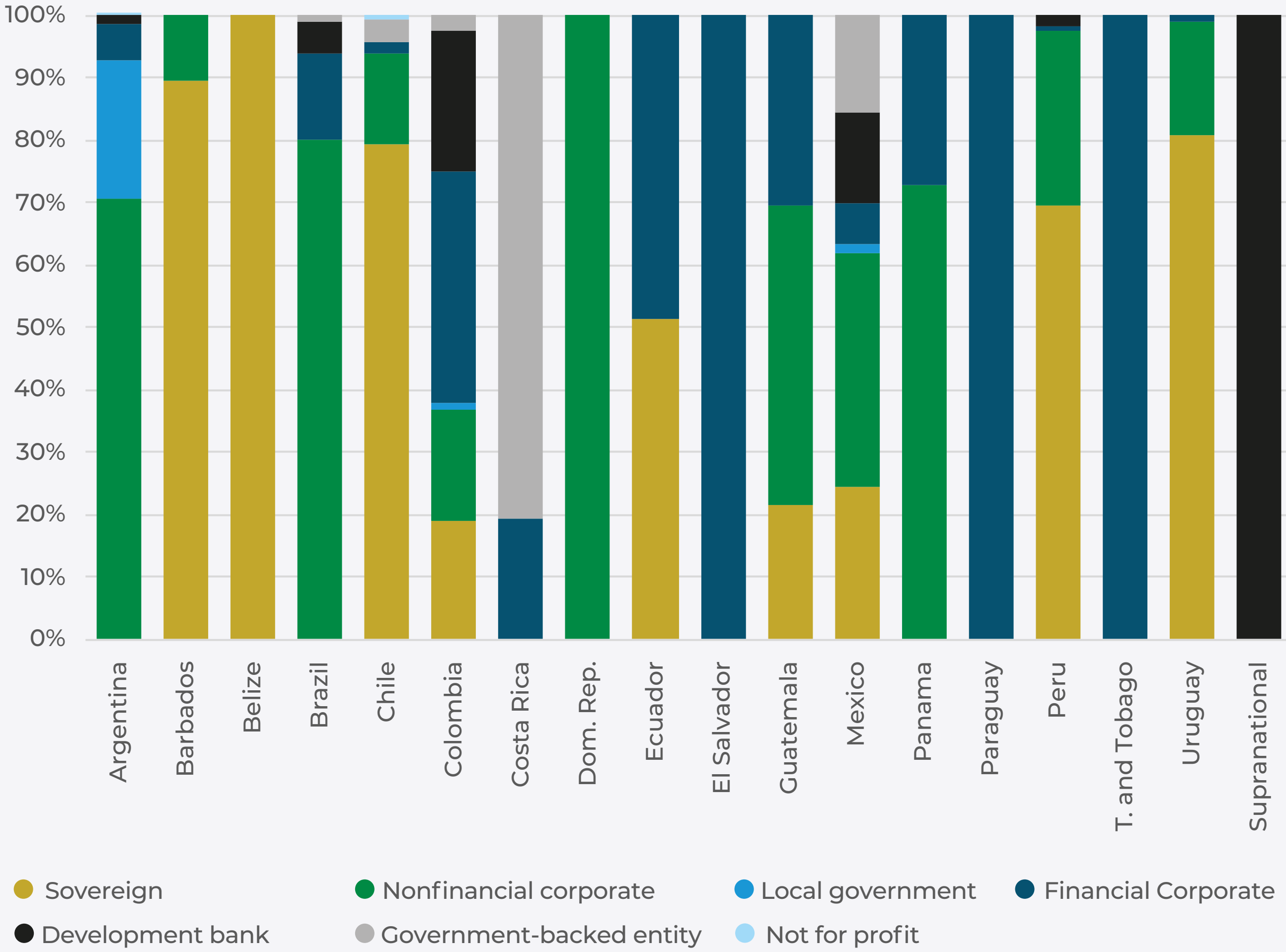
The distribution of GSS+ bond values reveals a significant discrepancy between issuance frequency and monetary value across the region. Chile exemplifies this pattern most clearly. While issuing fewer bonds than Brazil and Mexico (as shown in Figure 4.7), Chile accounts for the largest share (34.3 percent) of total market value. Thus, Chilean GSS+ bonds have larger average issuance sizes compared to those from Brazil, Mexico, and presumably other countries in the region. This disparity demonstrates that the number of bonds issued doesn't necessarily correlate with their financial magnitude in the regional GSS+ bond market, highlighting the importance of analyzing both metrics—issuance count and monetary value—when assessing a country's market participation in the sustainable finance landscape.

The proportional distribution of GSS+ bond issuance value varies significantly by issuer type across countries in the region, revealing significant heterogeneity in the institutional composition of bond issuers (see Annex 4.3 for a list of bond issuers). Sovereign issuers dominate the market in Barbados, Belize, Chile, Ecuador, Peru, and Uruguay, accounting for over 50 percent of the total issuance value in these nations (see Figure 4.9). In contrast, financial corporates lead the market in El Salvador, Paraguay, and Trinidad and Tobago. Meanwhile, nonfinancial corporates hold a significant share in Argentina, Brazil, the Dominican Republic, Guatemala, Mexico, and Panama. Government-backed entities play a particularly large role in Costa Rica and have some presence in Mexico, while development banks are active in Colombia and Mexico, but they primarily issue supranational bonds.[39]

Comparing these findings with previous figures helps explain why Chile accounts for the largest share of total GSS+ bond value in the region (34.3 percent), despite issuing fewer bonds than Brazil. This is because Chile's market is heavily weighted toward sovereign issuances, which typically involve higher-value bonds. A similar pattern is observed in Peru and Uruguay; while these countries rank 6th and 11th, respectively, in the number of bonds issued, they rank 4th and 8th in total bond value, likely due to their higher proportion of sovereign bonds.

39 Supranational entities are organizations that transcend national boundaries, facilitating cooperation and decision-making among member countries. These include regional development banks, international agencies, and similar institutions.

**Figure 4.9.**
Distribution of GSS+ Bond Issuance Value by Issuer Type and Country (2014-2022)



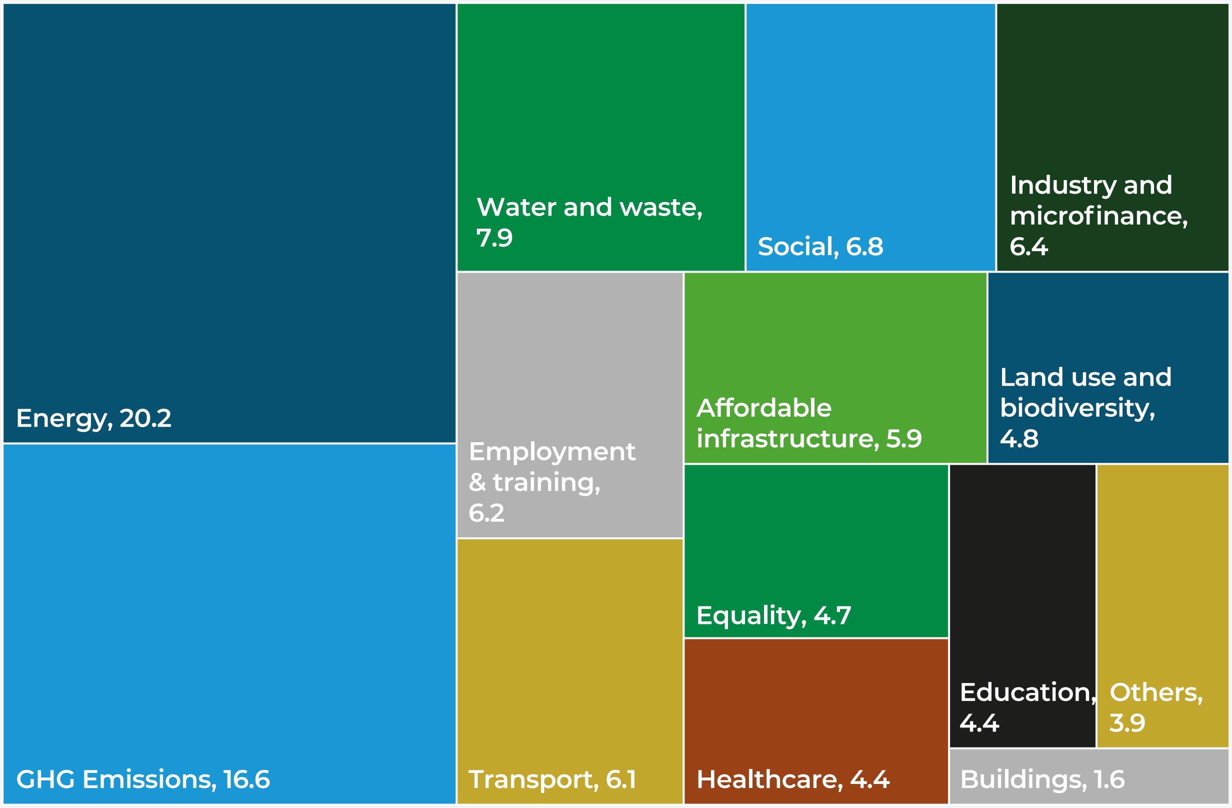

**Source:** Authors' elaboration based on Dagnino Contreras et al. (2023).

## What Do These Bonds Actually Finance?

Having described the evolution and composition of GSS+ bonds issued, the next step is to specify how much of these bonds go to infrastructure projects. The sustainable bond market shows distinct patterns across different instrument types. Between 2014 and 2022, green bonds focused on physical infrastructure, with renewable energy dominating at 52 percent of allocations, followed by sustainable transport at 23 percent and water management at 10 percent. These three categories—all closely tied to public infrastructure—accounted for 85 percent of green bonds, highlighting investors' preference for these sectors. Social and sustainability bonds emphasize human development through investments in physical infrastructure. Significant allocations were made to affordable infrastructure (13 percent in social bonds and 19 percent in sustainability bonds), as well as education (13 percent and 11 percent, respectively) and healthcare (10 percent and 14 percent, respectively).

Sustainability-linked bonds (SLBs) differ fundamentally from the other instruments as they are structured around performance targets rather than specific project financing. Greenhouse gas emissions KPIs accounted for 47 percent, with energy-related KPIs accounting for an additional 18 percent. Unlike use-of-proceeds bonds, these bonds represent a more flexible approach to sustainable finance, where issuers can achieve their commitments through various means, including but not limited to infrastructure development.

**Figure 4.10.**
Share of Total GSS+ Bonds by Use (2014-2022)




**Source:** Authors' elaboration based on Dagnino Contreras et al. (2023).

To facilitate analysis across this landscape, GSS+ bonds issued from 2014 to 2022 have been categorized into 15 groups, providing more systematic information about the relevance of financing directed toward public and physical infrastructure. Figure 4.10 displays a tree map visualization of sustainable bond allocations across various categories, with size representing the percentage of total financing. Energy (20 percent) and GHG Emissions (17 percent) dominate the allocation landscape, accounting for nearly 37 percent of all sustainable bond financing. These categories are linked to public infrastructure development, particularly energy generation facilities, grid improvements, and emissions reduction projects. However, in GHG, some KPIs related to the capture of GHG might not be directly related to infrastructure.

Water and waste management (7.9 percent) represents the third largest allocation, focusing on essential public utility infrastructure like water treatment plants, sewage systems, and waste management facilities. Still, it could also be oriented toward water efficiency, conservation, and infrastructure in farming. Transportation (6.1 percent) and affordable infrastructure (5.9 percent) also receive resources. Transportation likely includes public transit systems, roads, and rail networks, while affordable infrastructure encompasses housing and community facilities.

These categories have the clearest connection to public and physical infrastructure development: energy, GHG emissions, water and waste, transportation, and affordable infrastructure. Collectively, they account for approximately 56.7 percent of sustainable bond allocations, which demonstrates a strong orientation toward financing tangible infrastructure projects that can deliver environmental and social benefits through improved physical systems and facilities.[40]

While resilient infrastructure receives some financing through existing sustainable finance mechanisms, financial instruments explicitly designed for resilience investments remain limited both regionally and globally (Dagnino Contreras et al., 2023). Despite recent growth, adaptation funding still accounts for less than 10 percent of total global climate investment, with the majority flowing to mitigation initiatives (CPI, 2024). According to the Climate Bond Initiative, a key obstacle is the lack of investable project pipelines, primarily due to the absence of clear definitions for resilient investments

40 Healthcare (4.4 percent), education (4.4 percent), and buildings (1.6 percent) receive smaller allocations but are also related to physical infrastructure development, particularly social infrastructure like hospitals, schools, and public buildings.

(Michetti et al., 2023). Additionally, as the World Resources Institute explains, mitigation's focus on cutting GHG is more attractive to investors. Projects like renewable energy systems and electric vehicle manufacturing typically offer faster, more reliable returns than adaptation initiatives, which build defenses against uncertain future extreme weather events.

Examples of GSS+ thematic bonds with resilience-related financing allocation include Mexico's five sustainability bonds worth $543.4 million, financing water hazard early warning systems, emergency response protocols, public sanitation and hydraulic infrastructure construction and maintenance, among others. Also, Interchile S.A.'s $1.2 million green bond from 2021 finances transmission infrastructure and substation upgrades to enhance weather resilience (Dagnino Contreras et al., 2023).

In total, among the 654 thematic deals in Latin America and the Caribbean through 2022, 147 (22 percent) included resilience-related allocations, above the global 19 percent average. Development banks led resilience-related financing from Latin America and the Caribbean (46 deals), followed by sovereigns (32 deals) and nonfinancial corporates (31 deals). Country distribution shows Mexico (26 percent), supranational entities (24 percent), Chile (16 percent), Brazil (14 percent), Colombia (8 percent), Argentina (7 percent), and Ecuador (1 percent). Guatemala, Panama, Peru, and Uruguay each contributed 0.7 percent (Dagnino Contreras et al., 2023).

Despite the progress, the challenge is to attract greater financing to resilient infrastructure projects in the region. The next section discusses potential advantages of issuing GSS+ bonds as a means to mobilize additional resources for financing resilient investments. Then, the last section addresses the bottlenecks associated with the financing of resilient infrastructure projects and discusses ways to address them.

## The Greenium: Reality or Wishful Thinking?

The possibility of a lower premium for issuing GSS+ bonds compared to conventional bonds is often referred to as the "greenium," a combination of *green* and *premium*. A greenium is a lower yield or cost advantage that issuers may receive compared to conventional bonds.

To illustrate the concept, Figure 4.11 shows the yield performance of Germany's twin bond program from July 2020 to October 2022. Twin bonds consist of paired securities: a conventional government bond and a green bond that share identical maturity dates and coupon rates. The fundamental distinction lies in the use of proceeds; green bond revenues are exclusively allocated to green projects, while conventional bond proceeds fund general government expenditures. The figure depicts three key elements. The brown line tracks the conventional bond yield, the green line represents the green bond yield, while the green bars in the background plot the greenium in basis points: the yield spread between conventional and green bonds.

The yield to maturity percentage is shown on the left y-axis (ranging from approximately 1 percent to 2 percent), while the greenium appears on the right y-axis (0 to 10 basis points). The chart shows that both bond yields generally increased over the period, with a pronounced upward trajectory beginning in the second half of 2021. Throughout most of the timeframe, the conventional bond consistently yielded higher than its green twin, creating a greenium of around 6 basis points between January and October of 2022. A greenium of 6 basis points means that if a conventional bond yields 1.1 percent per year, an otherwise identical green bond yields 1.04 percent.

**Figure 4.11**

Performance of German Twin Bonds


**Source:** Ando et al. (2024).

This in turn provides an indication that there is some interest from investors in this type of instruments and that they are willing to give up some return on the bonds in exchange for the assurance that the resources will be used to fund specific initiatives. And it is therefore a positive signal for the ability of these instruments to mobilize additional resources for investment in resilient infrastructure. However, despite the simplicity of the concept and the fact that that investors are willing to accept lower yields for sustainable investments, the concept of greenium raises questions about its definition and measurement (see Box 4.4).

## BOX 4.4. The Concept of Greenium

In terms of the definition of the greenium, at least two issues arise. The first concerns its scope: does greenium exclusively refer to yield differentials between green bonds and conventional bonds, or does it encompass broader sustainable finance instruments such as social bonds, sustainability bonds, and sustainability-linked bonds? While the core definition of greenium refers to the yield spread between green bonds and their conventional counterparts, the empirical literature frequently extends this analysis to more diverse bond categories, potentially introducing conceptual inconsistencies.

The second concern relates to the underlying drivers of "greenium." Starks (2023) argues that investor motivations in sustainable finance markets fall into two distinct categories: "value" and "values." Value-oriented investors are primarily concerned with financial performance, analyzing how environmental, social, and governance (ESG) metrics might enhance portfolio returns. In contrast, values-motivated investors prioritize nonfinancial considerations and demonstrate willingness to accept lower financial returns to align investments with their ethical principles and social objectives.

This distinction is fundamental because existing greenium analyses often confuse these different motivations. To accurately assess green asset pricing dynamics, it is essential to disentangle the nonpecuniary benefits of environmentally responsible investing from purely financial considerations, such as hedging against climate-related financial risks (Yang, 2025). Conceptually, the greenium should be the premium arising from solely nonpecuniary considerations. (D'Amico, Klausmann, and Pancost, 2024).

Measuring greeniums presents some empirical challenges (see for example, Delgado et al., 2025). First, there are matching problems. Finding truly comparable conventional bonds to pair with GSS+ bonds is extremely difficult. Bonds differ in numerous characteristics, including maturity, coupon rate, liquidity, credit rating, sector, and covenant structure. Any mismatch in these parameters can distort greenium estimates. Even in the case of the German twin bonds used as an example, where maturity and coupon rates are identical and often presented as the perfect experiment to measure the greenium, their liquidity profiles vary.

Second, the GSS+ market is still new and developing. The green bond market has rapidly evolved, with changing standards, regulations, and investor sophistication. This creates temporal inconsistencies in greenium measurements across different time periods. Limited historical data, inconsistent reporting practices, and varying certification standards create significant data quality issues for quantitative analysis. These challenges highlight why greenium estimates vary widely across academic studies (Hong and Shore, 2023), undermining conclusive evidence about the true magnitude of the greenium in global bond markets.

Third, investors purchase green bonds for diverse reasons—financial return expectations, climate risk hedging, ESG mandates, or pure environmental preferences. Disentangling these factors (values vs value) to isolate the true greenium is methodologically complex. Even if data problems were resolved, this separation of motivational factors remains challenging in most cases, to the point that evidence is scarce, if not nonexistent, regarding research that can successfully identify why investors are willing to pay a premium and measure the true greenium (D'Amico et al., 2024).

Despite data and methodological challenges in measuring the greenium, from the literature on bond markets, some evidence is worth highlighting.

First, greenium estimates vary widely across academic studies, with findings ranging from zero (see Lau et al., 2022) to positive premiums of several basis points (Hong and Shore, 2023). This inconsistency could reflect both measurement difficulties and genuine market variations; however, on average a positive greenium is observed which is consistent with the theory.

Second, GSS+ governance frameworks and external review quality appear to significantly influence the greenium. Bonds with robust verification, transparent reporting mechanisms, and high-quality certification tend to command higher premiums (Caramichael and Rapp, 2024; Pietsch and Salakhova, 2025).

Finally, even when cost advantages exist for GSS+ bonds, these benefits are likely small or potentially negative when accounting for fees and compliance costs (certification, monitoring, and reporting). This burden could be particularly significant for complex green projects and small or first-time issuers (Caramichael and Rapp, 2024).

## Investing in Resilient Infrastructure: A Promising Strategy to Bridge the Infrastructure Gap

How to encourage investment in resilient infrastructure? The investment gap in the region is large, even for conventional infrastructure (Cavallo, Powell, and Serebrisky, 2020; Brichetti et al., 2021). Closing the gap requires increasing public and private investment. Therefore, relevant questions are: how to secure the necessary financing to increase investments; and how to develop funding mechanisms to repay that financing?

Alternative funding mechanisms depend on the project's characteristics and risks. This is particularly relevant for resilient infrastructure, which has distinct challenges. The main difference between resilient and conventional infrastructure lies in specific types of externalities and the timing of costs and benefits; resilience investments often incur immediate costs while benefits are realized over a longer timeframe, frequently affecting different groups.

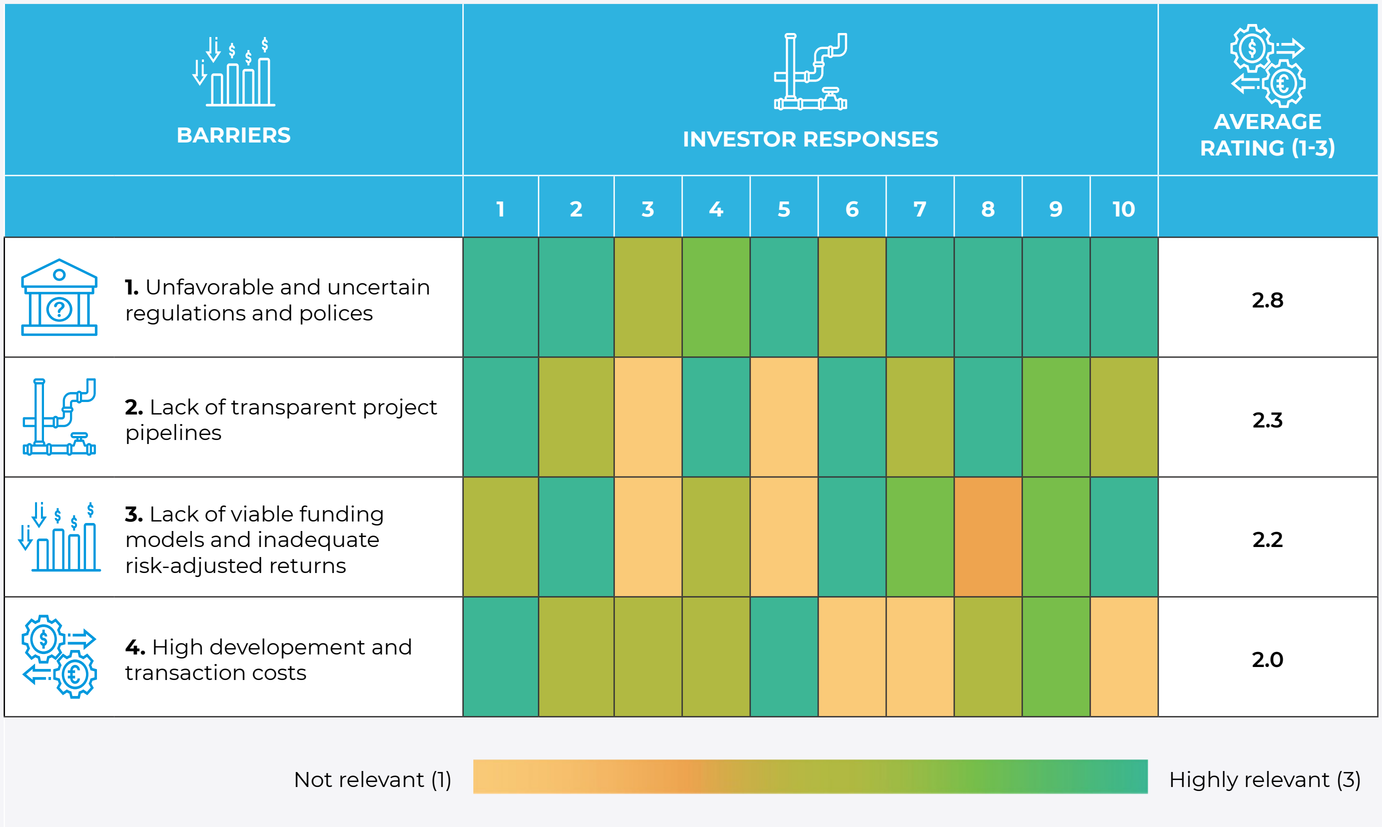
When it comes to actual investments, public investment in infrastructure is just approximately 1.7 percent of GDP and private investment is about 0.6 percent of GDP in the region. This is short of the 3.1 percent of GDP per year that the IDB estimates the region should invest to close existing gaps. However, a silver lining is that financing for public and private investment in resilient infrastructure is on the rise. Multilateral development banks contribute approximately 7 percent of public investment financing in Latin America and the Caribbean, and their climate-related finance commitments (a proxy for resilient infrastructure financing) have doubled from $38 billion in 2020 to $74.7 billion in 2023, particularly for low- and middle-income economies. Latin America and the Caribbean represents over 20 percent of the global climate finance market, with 60 percent coming from investment loans. Notably, sectors like water and sanitation, energy, and transport account for 40 percent of all MDB commitments to these countries. The private sector is also increasing its appetite for resilience-related infrastructure in Latin America and the Caribbean, raising the share invested in resilient infrastructure from 7.4 percent of total infrastructure investment in 2009 to 35 percent in 2024. While this trend is encouraging, more is required. Therefore, understanding how to make various sustainable infrastructure financing instruments—such as green, social, or sustainability-linked bonds—more attractive to investors remains a top policy priority.

Increasing investment in resilient infrastructure is a promising strategy to reverse the downward trend in overall infrastructure investment in the region, and to help close the infrastructure gap. What are, then, the main obstacles preventing more investment?

In 2020, the Inter-American Development Bank Group and Mercer, a consulting firm, conducted a survey to gain insights into the profile of infrastructure investors, specifically focusing on their needs and preferences related to investments, with an emphasis on social and environmental considerations. Nearly one hundred institutional investors, including commercial and development banks from Latin America and the Caribbean (44 percent of the sample), North America (25 percent), Europe (19 percent), and Asia Pacific (19 percent), were interviewed (see Figure 4.12).

**Figure 4.12.**

Barriers to Private Investment in Sustainable Public Infrastructure




**Source:** Frisari and Messervy (2021).

Survey results indicate that regulatory uncertainty is the most significant risk associated with investing in infrastructure projects. While this concern is highlighted in various global surveys, it is particularly pressing in emerging markets, where inconsistent policies and unexpected changes can disrupt investment plans and deter potential investors. Additionally, a lack of "bankable projects"— meaning projects that are considered financially viable and attractive enough to secure funding from investors— has been identified as a key barrier to investment (Frisari and Messervy, 2021). Social and environmental concerns also emerged as barriers. Inadequate planning for social conflicts or land management issues can result in cost overruns of up to 80 percent and time delays of more than 12 years for conflict resolution (Suárez-Alemán, Silva Zuniga, and INERCO Consultoría Colombia, 2020). In fact, survey results show that environmental and social concerns are among the main deal-breaker risks, along with governance and regulatory risks.

Addressing those concerns demands a suitable enabling environment characterized by robust regulatory, institutional, and planning frameworks for public infrastructure investment with private participation. Public-Private Partnerships (PPP) are so-called "upstream interventions" that can improve the enabling environment for private participation in infrastructure.[41] At the beginning of the XXI century, only one country in the region had the necessary regulations for PPP development. However, two decades later, nearly all countries have established sound and robust PPP policies and regulations (Economist Impact, 2022). This has led to a vibrant PPP market. Latin America and the Caribbean is a leading example of private participation in infrastructure development globally, with approximately 80 percent of such investments generated through PPPs (World Bank, 2025). Since 2023, the total investment in PPPs has increased by about 15 percent, and the number of PPP projects is up by 25 percent (Economist Impact, 2024). This growth is largely attributed to new sectors like social infrastructure and water and sanitation, which typically involve lower capital expenditures compared to transport and energy projects. While many scholars and practitioners acknowledge that creating a supportive regulatory environment is a crucial first step for developing any PPP market, this is not enough. Simply improving the legal and regulatory framework is not guaranteed to encourage greater investment. Other institutional conditions must be present, such as a solid institutional framework and the necessary capacities, which are frequently overlooked. These factors, along with political and social stability, are key drivers of PPP investment activity (Casady and Suárez-Alemán, 2025).

Beyond the enabling environment, there is a need to develop stable, well-prepared, and bankable project pipelines with a focus on social and environmental aspects to attract sustainable financing for infrastructure projects. This is precisely the area in which working on the structuring of funding mechanisms that guarantee the bankability—that is, the ability to attract financing—of the projects is key. In many cases, the absence of financing is not necessarily due to a lack of capital or interest from investors, but rather to the absence of clear and credible funding arrangements that specify how the financiers will be repaid. Specifically, uncertainty about who

41 See Iossa and Martimort (2015) for a model on the microeconomics of public-private partnerships.

will pay, under what conditions, and over what time horizon makes it difficult to assess the project's risk profile and, in turn, undermines its bankability.

Furthermore, in cases where the funding structure exposes the project to contingent or volatile sources of revenue (e.g., ad hoc transfers, politically sensitive user fees, or unreliable taxes), the associated risks may remain unmitigated or be deemed unacceptable by financiers. Without clear funding commitments, it becomes difficult to define the allocation of risks across actors, and it is even more difficult to design financial instruments—such as guarantees, blended finance structures, or risk-sharing arrangements—that can address those risks.

Therefore, establishing transparent, predictable, and enforceable funding arrangements is a precondition for structuring financially viable infrastructure projects. It enables the identification of potential risk exposures, clarifies the economic incentives of all parties involved, and allows public or multilateral actors to step in selectively with de-risking tools where market failures persist.

Environmental and community impacts, along with social equity, are among the weakest dimensions of sustainable PPP project preparation (Figure 4.13). Specifically, overall performance in Latin America and the Caribbean reveals inadequate environmental impact assessments, a lack of climate regulatory criteria, insufficient consultation with communities, and a failure to anticipate future changes or develop resilience and adaptability strategies. These strategies include selecting durable materials, adopting adaptable infrastructure approaches, and evaluating trends to reduce the risk of obsolescence. Additionally, only minimal progress has been made regarding sustainability in project preparation (see Figure 4.13). Notable exceptions include Ecuador, Jamaica, and Paraguay, while Brazil and Chile continue to lead, though there remains significant room for improvement.

**Figure 4.13.**
Sustainable Project Preparation Infrascope Evolution (2021-2024)


**Source:** Economist Impact (2024).

Specific risk mitigation instruments can be employed to effectively address the identified hazards. These may include political risk insurance, construction or credit guarantees, currency or interest rate hedging, and first loss protection or subordination, as highlighted by investors (Frisari and Messervy, 2021).

In sum, unlocking the full potential of resilient infrastructure in Latin America and the Caribbean hinges not only on mobilizing more resources but also on aligning funding structures with the unique characteristics of resilience investments. This requires a shift in mindset—from viewing resilience as a cost to recognizing it as a long-term value proposition. By embedding resilience into project design, clarifying funding commitments, and strengthening institutional capacity, the region can transform its infrastructure landscape into one that is not only more sustainable and inclusive, but also better equipped to withstand future shocks. The challenge is formidable, but the tools, actors, and momentum are already in place. What remains is the political will and coordinated action to turn ambition into durable impact.

CHAPTER 5

# From Awareness to Action: Advancing Resilient Infrastructure in Latin America and the Caribbean

The chapters in this volume have traced a clear narrative: infrastructure systems in Latin America and the Caribbean are increasingly vulnerable to climate variability and natural disasters, and the consequences of these disruptions are profound. The region's exposure to natural hazards—ranging from hurricanes and droughts to floods and wildfires—is not only high but growing, and the impacts are disproportionately borne by the most vulnerable populations. The convergence of low investment, aging infrastructure, rapid urbanization, and the imperatives of growth and development has created a critical juncture. The need to invest better, not just more, is no longer a choice but a necessity.

Chapter 2 provided a detailed diagnostic of how climate-related and geophysical hazards affect infrastructure systems. It distinguished between hazard, incidence, and impact, emphasizing that the transformation of a hazard into a disaster is not inevitable but contingent on the resilience of infrastructure and the capacity of institutions. Gradual climatic shifts—such as rising temperatures and changing precipitation patterns—alter both the demand for and the provision of infrastructure services. Extreme events destroy physical assets and disrupt service delivery, with cascading effects on households, firms, and macroeconomic performance. Importantly, vulnerabilities are not evenly distributed. Geographic exposure, economic structure, and the quality and redundancy of infrastructure systems shape risk profiles, with small island states and low-income countries facing particularly acute challenges.

Chapter 3 moved from diagnosis to action, presenting a rich and evolving policy and technical toolkit for resilience. It underscored the importance of robust risk assessment and prioritization frameworks, such as criticality and vulnerability assessments and decision-making under deep uncertainty.

Resilience is not just about reinforcing physical assets but about rethinking how infrastructure is planned, built, operated, and maintained. Diversification, decentralization, and redundancy in infrastructure networks are key elements for resiliency and nature-based solutions that leverage ecosystem services for risk reduction are growing in popularity. Demand-side adaptation, including early warning systems, behavioral interventions, and dynamic pricing, are underutilized but promising levers. Finally, regulatory and institutional frameworks must be designed to facilitate innovation, flexibility, and cross-sectoral coordination, recognizing the interdependencies among infrastructure sectors.

Chapter 4 addressed the financial dimension of resilience, focusing on the distinction between funding and financing. Resilient infrastructure often entails higher upfront costs, while the benefits—such as avoided losses and service continuity—accrue over time and present many challenges to be properly estimated. This temporal mismatch complicates the mobilization of capital and the design of equitable payment mechanisms. The region's infrastructure investment gap is large; public investment has averaged less than 2 percent of GDP since 2015, and private investment less than 1 percent. The landscape of sustainable finance is evolving and encompasses green, social, and sustainability-linked bonds, as well as blended finance and climate adaptation funds. While these instruments are expanding the pool of available capital, the lack of standardized definitions, limited pipelines of bankable resilient projects, and persistent regulatory and institutional barriers dampen their impact. Robust enabling environments—regulatory frameworks, project preparation facilities, and risk mitigation instruments—are needed to attract and sustain investment at scale.

Taken together, the chapters offer a framework for advancing resilient infrastructure in Latin America and the Caribbean. They provide guidance on what needs to be done and how to do it. Yet, they also reveal important gaps in our understanding. Chief among these is the limited availability of rigorous, context-specific evaluations of resilience-enhancing policies and investments. While many interventions are promising in theory or have shown success in isolated cases, there is still a lack of systematic evidence on their cost-effectiveness, scalability, and long-term outcomes. That is, while the menu of interventions is extensive—from nature-based solutions and decentralized systems to innovative financing instruments and adaptive planning—the empirical foundation to guide decision-making is still thin. One reason the evidence remains scarce is the absence of a clear, practical definition of resilience—what to measure in each context and each sector, and over which time frame—making it harder to evaluate. This knowledge gap is not merely academic; it has real-world implications for how governments, development institutions, and private actors prioritize investments, design regulations, and allocate scarce resources.

Moreover, the distributional impacts of resilience policies remain underexplored. Infrastructure disruptions disproportionately affect vulnerable populations, yet there is limited evidence on how resilience strategies can be designed to promote equity and inclusion. Similarly, while the importance of maintenance and lifecycle planning is widely acknowledged, data on actual performance and investment patterns are scarce. The financing landscape is evolving rapidly, but the effectiveness of new instruments to mobilize resources for resilience—particularly adaptation—requires further scrutiny.

Closing these knowledge gaps requires a concerted effort to build a research and data ecosystem around resilient infrastructure. This means investing in longitudinal studies and impact evaluations that can assess the effectiveness of resilience policies and projects over time. It also calls for developing standardized indicators and data collection protocols to track performance and outcomes across sectors and geographies. Collaboration between governments, academia, and development institutions is essential to share data, methodologies, and lessons learned, while pilot projects and innovation labs can serve as testing grounds for new approaches and generate actionable insights. Building this ecosystem will not only improve the quality of decision-making but also help align investments with the realities of climate risk and institutional capacity.

Despite these gaps, the trajectory is encouraging. The region is increasingly embracing resilience as a strategic priority, and the tools, actors, and momentum are in place to scale up efforts. Multilateral development banks are expanding their climate finance portfolios, governments are integrating resilience into planning and regulation, and private investors are showing growing interest in sustainable infrastructure. The rise of innovative financing mechanisms, the mainstreaming of nature-based solutions, and the adoption of adaptive planning frameworks all point to a shift from reactive responses to proactive strategies.

Ultimately, the path from risk to reliability is not linear. It requires continuous learning, institutional strengthening, and a commitment to evidence-based policymaking. However, it also offers a unique opportunity:

to build infrastructure systems that not only withstand shocks but also support growth, sustainability, and long-term prosperity. By investing in resilience today, the region can lay the foundation for a more secure, equitable, and dynamic future.

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# Annexes

## Annex 4.1.
## Eligible Green Project Categories

**Eligible categories of green projects include but are not limited to:**

- Renewable energy
- Energy efficiency (such as new and refurbished buildings, energy storage, district heating, smart grids, devices, and products)
- Pollution prevention and control (including reduction of atmospheric emissions, control of greenhouse gases, soil decontamination, waste prevention and reduction, waste recycling and efficient transformation of waste to energy)
- Sustainable management of natural resources and land use (including sustainable agriculture, sustainable animal husbandry, climate-smart agricultural inputs such as biological crop protection or drip irrigation, fisheries and aquaculture)
- Sustainable forestry, including afforestation or reforestation and the conservation or restoration of natural landscapes
- Conservation of terrestrial and aquatic biodiversity (including protection of coastal, marine, and watershed environments)
- Clean transportation (such as electric, hybrid, public, rail, non-motorized, and multimodal transportation, as well as clean energy vehicle infrastructure and harmful emissions reduction)
- Sustainable water and wastewater management (including sustainable infrastructure for drinking water, wastewater treatment, sustainable urban drainage systems, and river training and other forms of flood mitigation)

- Adaptation to climate change (including efforts to make infrastructure more resilient to the impacts of climate change, as well as information support systems such as climate observation and early warning systems)
- Products, production technologies and processes adapted to the Circular Economy (such as the design and introduction of reusable, recyclable, and refurbished materials, components and products, circular tools and services, and certified eco-efficient products)
- Green buildings that meet regionally, nationally, or internationally recognized standards or certifications for environmental performance

**Source:** Arciniegas et al. (forthcoming).

## Annex 4.2.
## Eligible Social Project Categories

### Eligible categories of social projects include but are not limited to:

- Affordable basic infrastructure (such as, drinking water, sewage, sanitation, transportation, and energy)
- Access to essential services (such as, health, education and vocational training, health care, financing, and financial services)
- Affordable housing
- Employment generation, and programs designed to prevent and/or alleviate unemployment arising from socioeconomic crises, including through the potential impact of SME and microfinance financing
- Sustainable food security and systems (such as physical, social, and economic access to safe, nutritious, and sufficient food that meets dietary needs and requirements, resilient agricultural practices, reduction of food loss and waste, and improved productivity of smallholders)

- Socio-economic progress and empowerment (such as equitable access to and control over assets, services, resources, and opportunities, equitable participation and integration in the market and society, and reducing income inequality)

**Source:** Arciniegas et al. (forthcoming).

## Annex 4.3. Type of Bond Issuers

1. **Sovereign:** National governments that issue bonds to finance public spending, budget deficits, or infrastructure projects. Examples are Chile's sovereign green bonds issued to finance sustainable infrastructure projects, or Brazil's government bonds (Tesouro Nacional).

2. **Nonfinancial Corporate:** Private or publicly traded companies outside the financial sector that issue bonds to raise capital for business expansion, acquisitions, or debt refinancing. Examples are CEMEX (Mexico) issuing sustainability-linked bonds, or Klabin (Brazil) issuing green bonds for sustainable forestry projects.

3. **Financial Corporate:** Banks, insurance companies, and other financial institutions that issue bonds to raise capital, fund lending activities, or meet regulatory capital requirements. Examples are Banco Santander Mexico issuing green bonds, or BTG Pactual (Brazil) issuing social bonds to finance SME lending.

4. **Development Bank:** Multilateral or national financial institutions that issue bonds to fund development projects in infrastructure, climate change, and poverty reduction. Examples are CABEI (Central American Bank for Economic Integration) or BNDES (Brazilian Development Bank) issuing sustainable bonds to finance renewable energy projects.

5. **Government-Backed Entity:** Organizations that, while not directly part of the government, have state support and issue bonds with an implicit or explicit government guarantee. Examples are NAFIN (Nacional Financiera) in Mexico or CORFO (Chilean Economic Development Agency) issuing bonds with government backing.

6. **Nonprofit Bond Issuers:** Nonprofit organizations, such as hospitals, universities, and charities, can issue bonds to finance capital projects, such as building facilities or expanding services. Examples are Universidad de Los Andes (Colombia) issuing bonds to fund campus expansion, or Fundación MAPFRE (with operations across Latin America) issuing social bonds.

7. **Local Government Bond Issuers:** Local governments, such as cities, states, provinces, or municipalities, issue bonds to finance public infrastructure projects like roads, schools, utilities, and transportation. These bonds are often called municipal bonds or subnational bonds. They can be backed by general tax revenues or by specific project revenues. Examples include Mexico City issuing green bonds to finance public transportation, or the State of São Paulo (Brazil) issuing bonds to fund water infrastructure projects.

**Source:** Arciniegas et al. (forthcoming).

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