CDRI
Coalition for Disaster Resilient Infrastructure

Global Infrastructure Resilience Working Paper

Views of Infrastructure Professionals

A global survey

GIR GIRS
2025 WORKING PAPER

This work is a product of the Coalition for Disaster Resilient Infrastructure (CDRI), as part of a working paper series under the ambit of the second Global Infrastructure Resilience Report (GIR 2025). This Working Paper on *"Views of Infrastructure Professionals: A Global Survey"*, highlights global perspectives from Infrastructure Professionals on the enabling conditions and barriers to resilient infrastructure. It may be accessed at https://cdri.world/resilience-dividend/global-infrastructure-resilience-report-second-edition/.

This document is a launch edition and may undergo minor changes subject to updates in the analysis.

All papers under the GIR 2025 Working Paper Series are available on the official website of CDRI, accessible on the web link mentioned above. They provide detailed background material, methodologies, analyses, and case studies for each chapter of the report. The papers will be released sequentially starting November 2025 through 2026.

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Author and lead technical partner

ICSI International Coalition for Sustainable Infrastructure

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Key implementation partner

Dissemination partners

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Acronyms

AI	Artificial intelligence
BIM	Building information modelling
CDRI	Coalition for Disaster Resilient Infrastructure
CRBE	Climate Resilient Built Environment
DRM	Disaster risk management
FGD	Focus group discussion
FSM	Federated States of Micronesia
GIRS	Global Infrastructure Resilience Survey
GIS	Geographic information system
IoT	Internet of Things
ISMEP	Istanbul Seismic Risk Mitigation and Emergency Preparedness Project
LiDAR	Light detection and ranging
NbS	Nature-based solutions
NGO	Non-governmental organization
NISTA	National Infrastructure and Service Transformation Authority
OECD	Organisation for Economic Co-operation and Development
PDC	Pacific Disaster Centre
PDNA	Post-disaster needs assessment
PPA	Power purchase agreement
PPP	Public–private partnership
PRIF	Pacific Regional Infrastructure Facility
SCADA	Supervisory control and data acquisition
SDG	Sustainable Development Goal
SENAPRED	Servicio Nacional de Prevención y Respuesta ante Desastres
SIDS	Small Island Developing States
SINAPRED	Sistema Nacional para la Prevención, Mitigación y Atención de Desastres
SME	Small and medium-sized enterprise
UNDRR	United Nations Office for Disaster Risk Reduction

Key Messages

The Global Infrastructure Resilience Survey (GIRS) for Experts and Professionals represents the most comprehensive study to date to capture the perspectives of infrastructure experts and professionals on infrastructure resilience worldwide. It draws on the perceptions of more than 3,000 professionals across over 100 countries, complemented by over 70 in-depth interviews and five focus group discussions involving more than 100 experts from 47 countries. GIRS provides valuable insights into the current state of infrastructure resilience and reveals critical gaps between policy ambition and on-the-ground implementation, indicating the vulnerability of infrastructure systems across the world.

The key messages presented here distil the survey's most significant findings, highlighting patterns that cut across regions and country income levels. The study results provide decision makers with evidence-based priorities for strengthening infrastructure resilience and emphasise that without addressing these fundamental gaps, infrastructure systems will be exposed to escalating climate and disaster risks.

GIRS findings reveal systemic barriers that constrain infrastructure resilience globally. Strengthening policies, standards, codes, and regulations emerges as the most significant governance action, with 50 percent of global responses identifying this as a top priority. However, even when regulations, codes, and standards exist, few of them adequately address infrastructure resilience or account for future climate risks. Enforcement remains limited, and compliance is often restricted to flagship projects, as reported by 30 percent of the respondents. Meanwhile, more than 50 percent reported limited inspection capacity or minimal enforcement mechanisms.

In several areas—including capacity, retrofitting, inclusion of future climate scenarios in risk assessments, and adoption of advanced technologies and nature-based solutions (NbS) for resilience—only 12–15 percent of the respondents reported comprehensive implementation. This 'implementation ceiling' reflects the structural limits under current institutional arrangements.

1

Strengthening policies, standards, codes, and regulations emerges as the most crucial governance action, with 50 percent of global responses identifying this as a top priority. However, even when regulations, codes, and standards exist, few of them adequately address infrastructure resilience and account for future climate risks. Further, their enforcement is limited and compliance is often restricted to flagship projects, as reported by 30 percent of the respondents.

2

Weaknesses in institutional and human capacity are central challenges. Globally, nearly 40 percent of the respondents reported insufficient public-sector capacity. Fragmented expertise, staff shortages, and poor retention undermine both public and private sectors' ability to implement resilience, especially at the local level. Limited capacity cascades across the system, weakening regulatory enforcement, data infrastructure, and risk assessment and fostering reactive rather than proactive planning.

3

There is systematic underinvestment in 'invisible' resilience measures—such as maintenance, retrofitting, and data systems—compared with more 'visible' interventions, such as post-disaster reconstruction and new infrastructure. Preventive measures are chronically underfunded, leaving critical vulnerabilities unaddressed. For instance, 60 percent of the respondents reported that funding meets less than a quarter of resilience needs.

4

Risk assessments are often inconsistently or poorly applied—only 26 percent reported consistent use; this dropped to 15 percent when future climate scenarios were included. While comprehensive data sets are rare, data often exists but is trapped in institutional silos, suffers from poor quality or incompatible formats, or is restricted by political and bureaucratic limits. Political reluctance to share information, monetization of data, and inter-agency competition further limit access and, ultimately, the effectiveness of risk assessments.

5

The study highlights an 'implementation ceiling' across aspects such as capacity, retrofitting, risk assessments, and adoption of advanced technologies, with only 12–15 percent, globally, reporting systematic application across the world. This indicates structural limits to resilience under current institutional arrangements.

6

Gaps in professional capacity block the scaling of solutions—only 15 percent reported consistent use of nature-based infrastructure and 12 percent reported the uptake of advanced technologies. While these solutions are well known, they largely remain in the pilot stages or limited to flagship or donor-driven projects—held back by institutional inertia, training gaps, and conservative professional practices.

7

Bridging capacity gaps through professional development and education reform is essential to implement resilient infrastructure. Skilled practitioners can ensure that resilience policies do not remain only on paper but are enacted effectively, creating infrastructure that withstands climate and disaster risks.

Weaknesses in institutional and human capacities represent central challenges, with nearly 40 percent of the respondents reporting insufficient public-sector capacity and only a small minority rating it as adequate. Fragmented expertise, staff shortages, and poor retention undermine both the public and private sectors' ability to implement resilience. This perpetuates a cycle in which weak capacity constrains implementation, reduces political support, and eventually hinders professional and institutional development. Limited capacity cascades across the system, impairing regulatory enforcement, data infrastructure, and risk assessments while fostering reactive rather than proactive planning. Addressing any single element without strengthening others is therefore unlikely to yield meaningful improvement.

Evidence from the consultation further points to a fundamental lack of shared understanding of what 'resilient infrastructure' means across decision-making levels. Several stakeholders equate resilience solely with disaster response or hardening physical assets, thus overlooking the systemic, social, and adaptive dimensions required to withstand future risks. Without a common language and clear, practical guidance on resilience, decision makers struggle to translate high-level commitments into actionable plans, and technical experts are unsure about how to design, deliver, and evaluate resilience outcomes. This ambiguity reinforces fragmented action and slows progress across the infrastructure system.

Coordination remains short-term and crisis-driven. Agencies often collaborate effectively during disasters, but preparedness, mitigation, and resilient recovery remain fragmented. Political turnover and weak municipal capacity further exacerbate vulnerabilities. Without systemic reforms to strengthen coordination, build local staffing and technical capacity, and ensure continuity in governance, resilience strategies will remain aspirational and national policies will fail to translate into locally delivered, resilient infrastructure.

Investment priorities demonstrate a clear pattern of systematic underinvestment in 'invisible' resilience measures, such as maintenance, retrofitting, and data systems, compared with 'visible' interventions, such as post-disaster reconstruction and new infrastructure. Sixty percent of the respondents reported that funding meets less than a quarter of resilience needs. Preventive measures are chronically underfunded, with less than a quarter of retrofitting needs being met. Political economy factors, including electoral cycles and public perception, often influence resource allocation and professional attention. This results in the prioritization of initiatives that generate immediate visibility over long-term risk reduction.

Professional capacity gaps further inhibit progress, with only 15 percent reporting consistent use of nature-based infrastructure and 12 per cent noting the same for advanced technologies. Advanced technologies and NbS are becoming increasingly known, yet they either remain in the pilot stages or are confined to flagship or donor-driven projects. Only a small proportion of respondents reported consistent use of advanced technologies; NbS are rarely mandated. Institutional inertia, gaps in professional training, and conservative practices among engineers, planners, and financiers prevent these solutions from scaling.

Risk assessments are often inconsistently or poorly applied, with only 26 percent of the respondents reporting consistent use, which dropped to 15 percent when future climate scenarios were included. Comprehensive data sets are rare; even when available, they are fragmented, inaccessible, or poorly integrated with infrastructure planning, limiting the effectiveness of risk assessments.

Regional and income-level variations show that resilience does not follow linear development trajectories. Low-income countries with donor-supported initiatives may achieve higher coverage of pilot programmes, while some middle-income regions demonstrate human resource strengths despite having broader institutional constraints. Wealthier nations face challenges in maintaining ageing assets, whereas developing countries contend with weak governance structures. These patterns highlight opportunities for cross-regional learning and the need for context-specific strategies.

Equally critical is equipping engineers and other practitioners with the knowledge and skills necessary to implement resilience in practice. This includes understanding the principles of resilience and being able to apply, interpret, and validate relevant standards and codes in real-world projects. Strengthening capacities in inspection, monitoring, and performance evaluation ensures that resilience measures are enforced consistently. Engineering education must simultaneously be reformed to embed resilience thinking from the outset. By working closely with academia to shape the next generation of professionals, universities can incorporate resilience into curricula and equip future engineers and infrastructure specialists with the competencies needed to design, operate, and maintain infrastructure that can withstand climate impacts and other risks. Both upskilling current practitioners and educating future professionals are essential for translating policies and regulations into tangible, durable, and resilient infrastructure on the ground.

Taken together, the findings indicate that infrastructure resilience is constrained less by the lack of appropriate technical solutions than by deficiencies in governance, institutional capacity, and systemic integration. Building resilience requires coordinated institutions, professional transformation, robust risk assessment, and investment prioritization aligned with long-term risk reduction. Addressing these challenges will require sustained political commitment, proactive engagement across government, and active private-sector participation to shift the focus from short-term visibility to long-term adaptation and resilience.

1. Introduction

As infrastructure systems face escalating risks from disasters and climate change, there is an urgent need to understand how they can better withstand shocks, adapt to emerging risks, and recover quickly. To address this, CDRI commissioned the International Coalition for Sustainable Infrastructure as the lead technical partner to deliver the GIRS for Infrastructure Experts and Professionals.

The survey examined six core themes: governance and institutions, finance, risk assessments, nature-based solutions (NbS), advanced technologies, and monitoring systems. Drawing on the perspectives of infrastructure professionals—including engineers, planners, policymakers, and private-sector actors across regions and countries—GIRS provides a unique global picture of strengths, deficiencies, and opportunities for building resilience. It offers an integrated assessment of national infrastructure systems, revealing critical gaps between resilience policies and their real-world application. Rather than reflecting a theoretical framework, the evidence base captures operational realities and the challenges practitioners face in strengthening infrastructure resilience in diverse contexts. These findings will inform CDRI's Global Infrastructure Resilience report, GIR 2025.

This working paper presents the findings of this global study and is structured as illustrated in **Figure 1**.

Figure 1

Structure of the working paper

Source: Authors' analysis

1.1 Objectives of the GIRS for Infrastructure Experts and Professionals

The following were the key objectives of the study:

i. **Create awareness on the resilience of global infrastructure systems:** Assess the capacity of infrastructure systems globally to absorb, respond to, and recover from the repercussions of disasters, based on the perspective of professionals working in infrastructure sectors. Generate insights into infrastructure resilience across regions, countries, and institutional structures.

ii. **Understand institutional, technical, and human capacities:** Collect and analyse data on institutional, governance, and human capacities in infrastructure across different nations to comprehend the systemic differences in management and how these could be addressed.

iii. **Gather broader perspectives:** Compile diverse viewpoints through a multilingual online questionnaire, expert interviews, and focus group discussions (FGDs) to create an integrated picture of national infrastructure systems from the responses of local experts engaged in the design, construction, operations, and repair of infrastructure systems. Highlight good practices in infrastructure resilience.

iv. **Identify areas for improvement:** Using the insights gained from the survey, make recommendations to help countries identify the institutional, policy, and capacity aspects of infrastructure systems that require improvement, to enhance their ability to withstand disasters, adapt to changing risks, and serve communities when they need it most.

v. **Support global knowledge-sharing and policy development:** Build an evidence base to inform CDRI's GIR 2025. Provide actionable insights for policymakers, practitioners, and researchers to help them align resilience strategies with global frameworks (see **Box 1**).

Box 1

Relevance of the GIRS for Infrastructure Experts and Professionals to global frameworks

The survey aligns closely with key global frameworks that guide sustainable and resilient development. By assessing the systemic barriers to resilient infrastructure, it supports the UN 2030 Agenda for Sustainable Development and directly contributes to several Sustainable Development Goals (SDGs), particularly SDG 9 (industry, innovation, and infrastructure), SDG 11 (sustainable cities and communities), and SDG 13 (climate action). Its focus on reducing vulnerability and enhancing preparedness reflects the Sendai Framework for Disaster Risk Reduction, which emphasizes proactive risk management, resilience-building, and minimizing disaster impacts through systemic change. Further, by highlighting the need to incorporate future climate scenarios into risk assessments and investment decisions, the survey reinforces the objectives of the Paris Agreement, particularly the commitment to enhance adaptive capacity, strengthen resilience, and reduce climate-related losses and damage. In doing so, it provides a practical evidence base to help countries translate these global commitments into action at national and local levels.

1.2 Survey Coverage and Respondent Characterization

This edition of GIRS captured perspectives from infrastructure experts and professionals who engage in the planning, delivery, and management of infrastructure systems. This is the largest survey of its kind, focusing specifically on resilience. The survey gathered comprehensive data through online questionnaires in six languages, reaching over 3,000 respondents across more than 100 countries. Over 75 in-depth interviews and five FGDs (Australia/Pacific Small Island Developing States [SIDS], Brazil, Egypt, and India), engaging more than 100 experts from 47 countries, helped deepen the understanding of regional and contextual variations further.

The primary target audience for the survey were professionals engaged in the downstream phases of infrastructure, that is, construction, operations, maintenance, and repairs. These practitioners offered real-world perspectives on how institutions, policies, and governance function in practice. Respondents of the online questionnaires included infrastructure engineers, technical specialists, planners, designers, and operations personnel; this ensured broad coverage across disciplines and encompassed the different stages of the infrastructure life cycle.

The online questionnaires achieved balanced representation across organization types. Roughly 30 percent of the respondents were from government, 45 percent from the private sector—including architecture, engineering, and construction firms, as well as private investors—and 24 percent from non-profit actors, such as non-governmental organizations (NGOs), intergovernmental organizations, academia, and multilateral development banks (**Figure 2**).

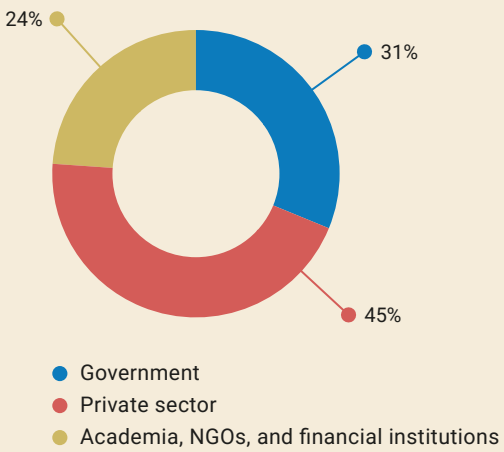
By job function, nearly half the respondents were consultants, planners, designers, or contractors, while about a quarter held managerial or leadership roles (**Figure 3**).

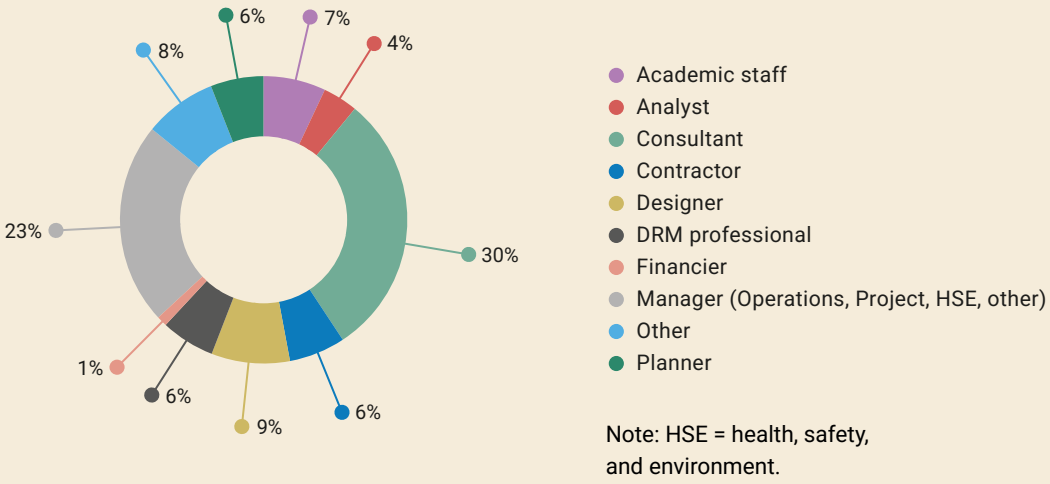
Respondents were also asked to identify the infrastructure sector with which they had the most experience. This helped ensure that responses were attributed to the relevant infrastructure sectors and drew on the respondents' respective areas of expertise. In the analysis that follows, these sectors were consolidated into two categories, buildings and other infrastructure—aggregating the sectors that were offered as options in the survey, that is, transportation, energy, water and sanitation, telecommunications, emergency services and disaster response, environmental and natural resources, and waste management—to align with the analysis in CDRI's Global Infrastructure Risk Model. Around 30 percent of the respondents specialized in buildings and 70 percent in the other infrastructure sectors (**Figure 4**).

Figure 2

Percentage of respondents by organization type

Source: Authors' analysis





Note: HSE = health, safety, and environment.

Figure 3

Percentage of respondents by job function

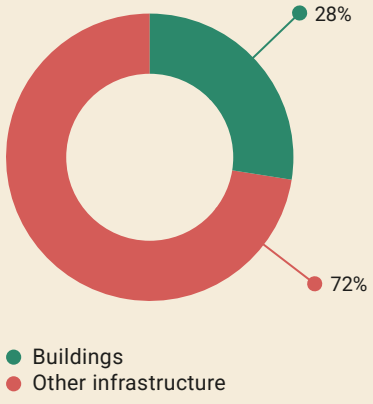
Source: Authors' analysis

Responses originated from global regions, with about a third from Sub-Saharan Africa. Smaller shares came from Europe and Central Asia, Latin America and the Caribbean, South Asia, and East Asia and the Pacific. The smallest proportion of responses was from North America and the Middle East (**Figure 5**). Respondents were balanced across country income groups, with approximately a third from high-, upper-middle-, and lower-middle-income countries and a smaller share from low-income countries (**Figure 6**). The number of responses for each region and country income group reached a statistically significant level.

Figure 4

Percentage of respondents by sector

Source: Authors' analysis

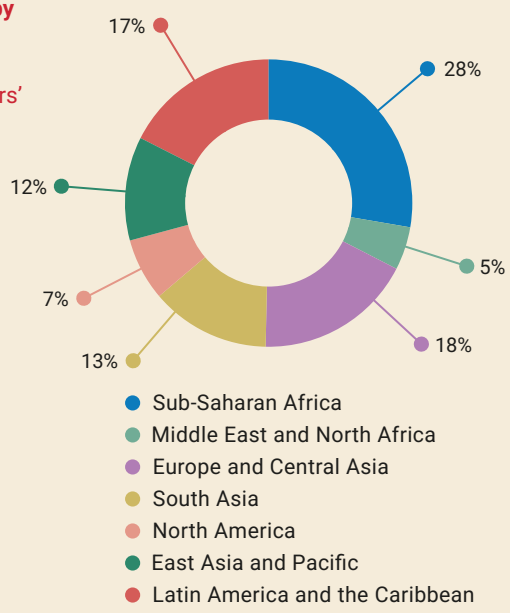


Note: Buildings (housing, public institutions, commercial); other infrastructure sectors (transportation, energy, water and sanitation, telecommunications, emergency services and disaster response, environmental and natural resources, waste management).

Figure 5

Percentage of respondents by region

Source: Authors' analysis



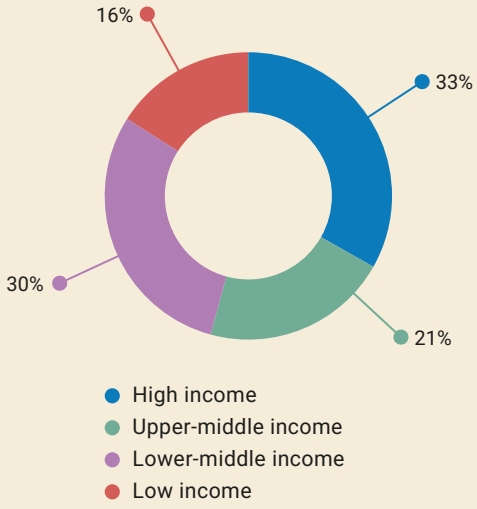


Figure 6

Percentage of respondents by country income level

Source: Authors' analysis

1.3 Methodology

The GIRS for Infrastructure Experts and Professionals employed a comprehensive mixed-methods research design that integrated quantitative and qualitative data collection to examine infrastructure resilience from multiple perspectives.

The study utilized a convergent design methodology, wherein quantitative data and qualitative insights were collected simultaneously rather than sequentially. The survey methodology incorporated multiple data collection instruments to capture both broad patterns and contextual depth. The primary tools included structured questionnaires for quantitative data, and in-depth interviews and FGDs for qualitative insights.

Data analysis was organized around six core thematic areas that will be covered in GIR 2025: governance and institutions, finance, risk assessments, NbS, advanced technologies, and monitoring systems. This structured framework provided a systematic approach to examining infrastructure resilience across multiple dimensions while maintaining analytical coherence throughout the study.

The quantitative component[1] employed multi-level analytical techniques, including descriptive statistics, market segmentation analysis, and cross-tabulation methods. Survey data was analysed as follows:

- Global trends across all survey data.
- Organization type: Public sector, private sector, and non-profit.
- Infrastructure sector: Building sector and other infrastructure sectors, which include transportation, energy, water and sanitation, telecommunications,

[1] Disclaimer: The questionnaire results are presented by grouping respondents according to their country's income level and region. The data were also analysed by respondents' infrastructure sector, type of organization, and country vulnerability level. While the report discusses these additional findings where relevant, charts for these breakdowns are not included.

emergency services and disaster response, environmental and natural resources, and waste management.

- Country income level analysis using the World Bank income groupings: high income, upper-middle income, lower-middle income, and low income.
- Regional analysis following the CDRI's first Global Infrastructure Resilience report (GIR 2023) classification: South Asia, Europe and Central Asia, Middle East and North Africa, East Asia and the Pacific, Sub-Saharan Africa, Latin America and the Caribbean, and North America.
- Vulnerability-level analysis: Countries were classified using the Notre Dame Global Adaptation Initiative's Country Index, an open-source tool that measures current vulnerability to climate disruptions. For analysis, countries' vulnerability scores were grouped into three categories—low, middle, and high vulnerability—to enable clearer comparisons across different levels of climate risk (University of Notre Dame, 2024).

The questionnaire results are presented by grouping respondents according to their country's income level and region. The data were also analysed by respondents' infrastructure sector, type of organization, and country's vulnerability. While the report discusses these additional findings where relevant, charts for these breakdowns are not included.

Qualitative data from the interviews and FGDs underwent rigorous processing, involving complete transcription, systematic thematic coding, and comprehensive fact-checking procedures. This qualitative analysis provided a deeper explanatory context for the quantitative findings. The thematic coding process ensured that the qualitative insights could be systematically compared with the questionnaire results during the convergent-analysis phase.

Secondary data sources were incorporated to further enhance the robustness of the conclusions. Further details are available in Annexure A.

2. Common Analytical Framework

GIR 2025 uses a common framework to analyse infrastructure resilience. This section introduces the concepts and definitions used throughout the main report and its working papers.

According to the DRI Lexicon (CDRI, 2023a), infrastructure comprises the "individual assets, networks and systems that provide specific services to support the functioning of a community or society." Disaster-resilient infrastructure is defined as "infrastructure systems and networks, the components, and assets thereof, and the services they provide, that can resist and absorb disaster impacts, maintain adequate levels of service continuity during crises, and swiftly recover in such a manner that future risks are reduced or prevented." Thus, it can be seen that the resilience of infrastructure assets, networks, and services depends on their capacity to (i) resist and absorb the shocks caused by disasters; (ii) respond to the damages and maintain at least basic levels of service continuity during crises; and (iii) restore services as quickly as possible, incorporating the lessons learned from the disaster to reduce future loss and damage.

It is also essential to consider the resilience of infrastructure service users, which depends on their ability to (i) be better prepared and utilize the information provided by early-warning systems to reduce the shock of disasters; (ii) find supplementary or alternative means to failed infrastructure services (e.g., back-up generators for electricity or alternative modes of transport); and (iii) learn from disasters, along with the infrastructure agencies, so that they are better prepared for future disasters.

Resilience across these three levels—infrastructure assets, services, and users—should be understood not just as the ability to withstand the next disaster but also as the capacity to respond to and recover from it. Building resilience in infrastructure assets and systems requires a comprehensive understanding of the resilience cycle. **Figure 7** illustrates this cycle and the three capacities that an individual infrastructure asset should possess. In this figure, the vertical axis represents the performance level of an infrastructure asset, and the horizontal axis corresponds to time. An asset will have a normal operating performance level, indicated by the green line on the left-hand side of the graph.

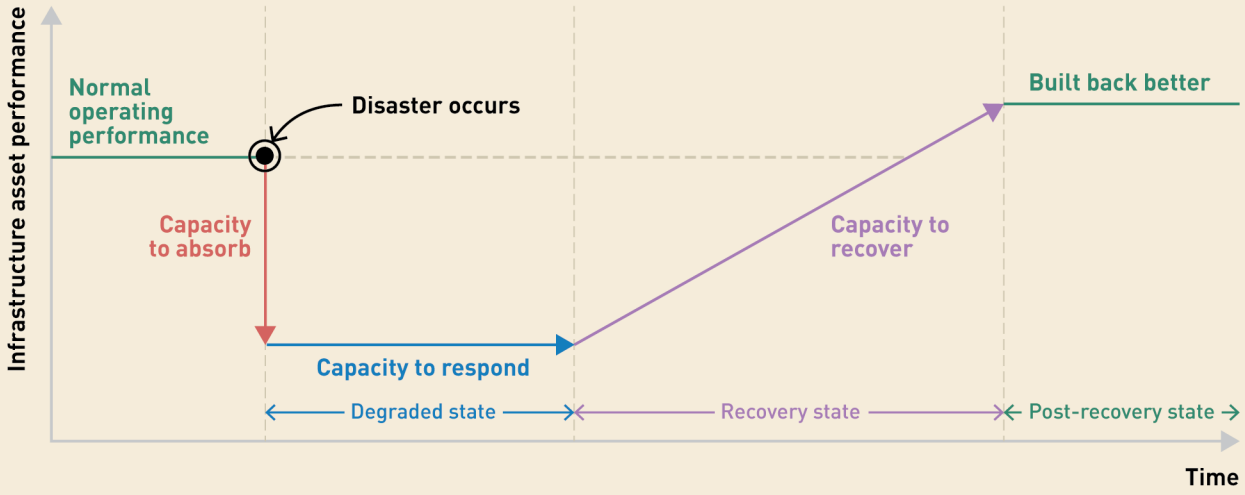


Figure 7

Three capacities for resilient infrastructure

Source: Adapted from CDRI (2023b)

When a disaster occurs, the normal operating performance of an infrastructure asset may drop to a lower state—even to zero for a total failure of the asset, such as when a bridge is destroyed by a flood or a road covered by a landslide. The magnitude of the drop depends on the capacity of that asset to absorb disaster shocks, represented by the red line. The asset remains in a degraded state for a period, represented by the blue line. During this time, emergency and clean-up actions, as well as repair and reconstruction work, are undertaken. In some cases, the infrastructure agency also works to partially restore basic services. The infrastructure asset then enters the recovery phase, represented by the purple line. The lessons learned from the disaster, including updated risk assessments that integrate new hazard data and climate change projections, play a crucial role in the repair and reconstruction phase. The reconstruction phase also offers an opportunity to incorporate NbS, adopt stronger resilience standards for the asset, or leverage new technologies for resilience. The recovery phase can restore the normal operating performance of the asset or 'build back better', represented by the green line on the right-hand side of the graph.

Many infrastructure agencies focus on enhancing the capacity to absorb shocks by strengthening standards and regulations, implementing retrofit programmes for existing assets, and improving construction supervision for new, more resilient assets. They may also expand maintenance and repair programmes to strengthen assets in preparation for future disasters (e.g., during the cyclone season). However, focusing only on the capacity to absorb is insufficient. The duration and severity of disruptions to economies and livelihoods are directly proportional to the time it takes for the asset to return to its earlier (or an enhanced) level of operation. The longer it takes for the infrastructure asset to respond and recover, the larger the impact on households, businesses, and communities. Figure 7 can be used to understand the resilience cycle for infrastructure networks and services, where the capacity to recover services depends on the network redundancy, and building back better requires a network analysis of vulnerabilities.

The capacity of users—whether individuals, households, communities, or businesses—to respond to infrastructure failures depends on effective communication with infrastructure service providers and their resilience in finding alternative means of service provision.

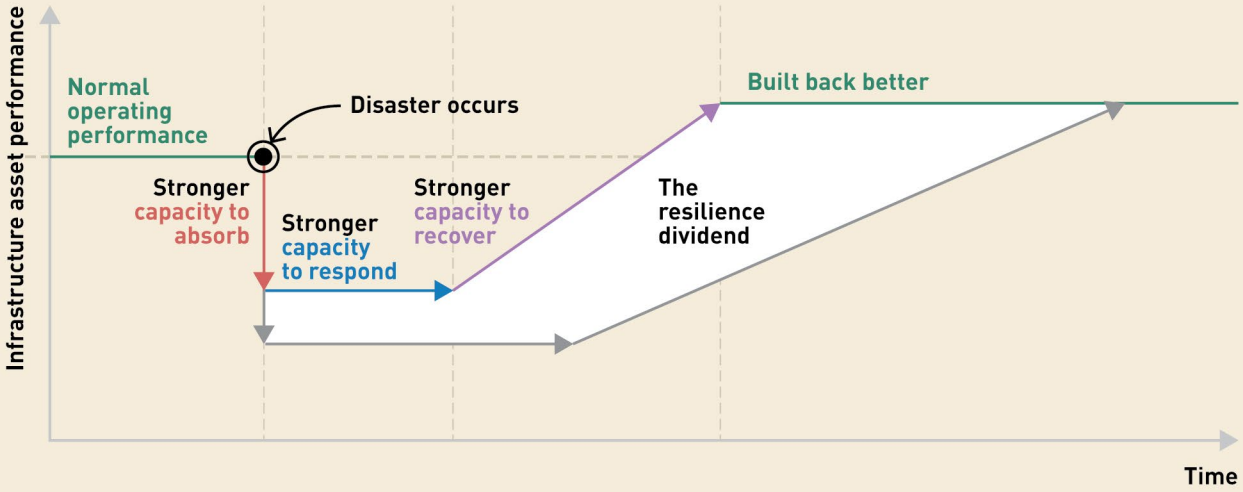


Figure 8

The resilience dividend obtained by strengthening the three capacities for resilient infrastructure

Source: Adapted from CDRI (2023b)

As discussed earlier, building the resilience of infrastructure systems requires agencies and asset managers to strengthen not only the capacity to withstand disasters but also the ability to respond to shocks and recover quickly. **Figure 8** shows the resilience-building process that could enhance the three capacities. An infrastructure agency or asset owner can implement several measures to strengthen the capacity to absorb (shorter red line on the left-hand side of the graph). These include developing enhanced maintenance, repair, and retrofit programmes or using systems that translate the early-warning notices sent by hydro-meteorological services into preparatory actions to protect assets.

A stronger capacity to respond requires infrastructure agencies to be better prepared for disasters. Robust coordination plans with the national disaster risk management agency are essential, as well as with other emergency services and infrastructure agencies or utilities that provide linked services that could fail in a cascade after disasters. Other actions that would boost preparedness include plans in place to remove debris from the asset; advance procurement of standby repair services, including strategic location of repair materials; and the use of new technologies such as drones for rapid assessment and evaluation of damage.

Finally, infrastructure agencies or asset owners can improve their ability to recover (represented by the purple line) by conducting post-disaster evaluation and learning activities; identifying new tools (such as NbS or new technologies) to be incorporated in the repaired asset; and enhancing resilience standards in the repair and reconstruction efforts.

Strengthening the three capacities will lead to damage resilience and protect assets from performance degradation. The response time in the event of a future disaster of similar magnitude can improve with more effective repair and reconstruction processes in place. This will also lead to a faster restoration of services and, consequently, lower the impact of disasters on livelihoods and the economy. The white area in Figure 8 visually represents the 'resilience dividend' of such efforts.

This framework has been applied consistently across the main GIR 2025 and its working papers.

3. Governance and Institutions

This section presents the survey's findings on topics related to governance and institutions for resilience (**Figure 9**). Research questions were designed to explore how institutional capacity, policy frameworks, and coordination mechanisms influence infrastructure resilience. They examined whether governments are prioritizing retrofitting and implementing effective improvements, the extent of in-house capacity to embed resilience planning, and the role of the private sector in supporting these efforts. They also investigated how disaster risk management (DRM) agencies align with infrastructure institutions in terms of preparedness, response, and recovery, and whether regulations, codes, and standards for resilient infrastructure are both comprehensive and efficiently enforced.

Figure 9

Structure of Section 3, Governance and Institutions

Source: Authors' analysis

3.1
Public Sector's Capacity and Availability of Human Resources

3.2
Private Sector's Technical Capacity and Availability of Human Resources

3.3
Retrofitting Programmes

3.4
Coordination Capacity for Hazard Mitigation, Disaster Preparedness, and Disaster Response and Recovery

3.5
Existence and Enforcement of National Regulations, Codes, and Standards

3.1 Public Sector's Capacity and Availability of Human Resources

Institutional capacity refers to the systems, processes, and governance frameworks through which the public sector directs resilience efforts. Robust institutional arrangements ensure that climate and disaster risks are systematically integrated across the infrastructure life cycle, supporting coherent, risk-informed decision-making (Royal Academy of Engineering, 2025). Institutional strength and human resource capacity are mutually reinforcing (Organisation for Economic Co-operation and Development [OECD], 2019), with each underpinning the effectiveness of the other.

Global trends

Nearly half of the respondents—46 percent for institutional capacity and 43 percent for human resources—indicated significant variability within their countries' public sectors. Some agencies are well equipped, while others are facing critical gaps. Overall, 15 percent of the respondents said their countries have 'adequate' institutional capacity, but 38 percent described it as 'limited'. Similarly, 24 percent considered human resources availability for infrastructure resilience 'adequate', and 33 percent said it was 'limited'. These mixed results suggest that resilience implementation varies widely even within countries.

Crucially, this assessment is consistent across respondents' organizations: Just under half of both government and private-sector participants reported 'variable' institutional capacity, while the majority of the remaining respondents rated it as 'limited'. Perceptions were somewhat more pessimistic among academic, not-for-profit, and financial institutions. This consensus prevailed across infrastructure sectors and vulnerability levels.

Looking through a vulnerability lens, moderate-vulnerability countries stand out for having the lowest adequacy and the highest limitations, followed closely by low-vulnerability countries.

KEY FINDING 1

Institutional capacity and human resource availability for infrastructure resilience remain uneven worldwide. Only around 15 percent of the respondents rated institutional capacity as 'adequate', while nearly half said it was 'variable' and close to 40 percent considered it 'limited', with strengths uneven across ministries and sectors. As for human resources, 24 percent rated them as 'adequate', and around one-third believed they were 'limited'. Fragmentation, staff retention challenges, and policy implementation gaps compound the vulnerabilities. In high- and upper-middle-income countries, frameworks are more advanced, but local execution is hindered by staff shortages, limited resources, and dispersed responsibilities. In lower-middle- and low-income countries, weaknesses are systemic due to fragile institutions, difficulty retaining skilled professionals, and dependence on donor support.

Regional analysis

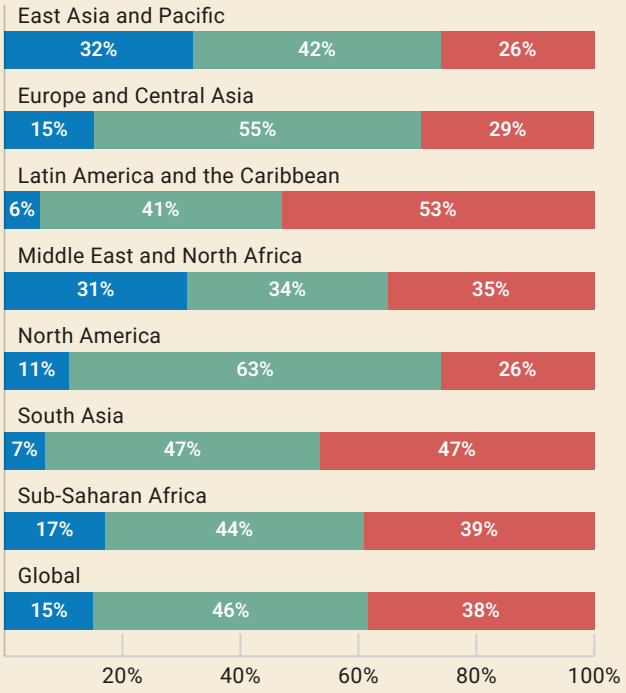
When data on the public sector's institutional capacity and human resources availability is examined by region, further insights emerge (**Figures 10 and 11**). Respondents from Latin America and the Caribbean expressed the highest levels of concern when compared with participants from all other regions: 53 percent rated institutional capacity for infrastructure resilience as 'limited'—that is, requiring substantial external support—and only 6 percent considered it 'adequate'. The experts interviewed from this region highlighted political instability; financial volatility; institutional silos; resistance to change, including reluctance to adopt new technologies; lack of technical expertise; and severe understaffing as major challenges for infrastructure ministries and agencies. Nevertheless, they noted that selected central agencies and specific sectors demonstrate stronger capacity and awareness.

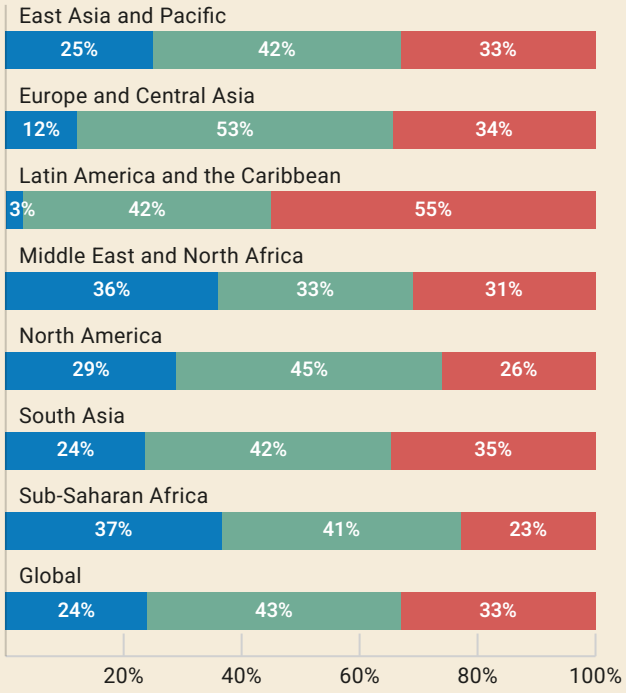
Survey data from North America presents a contrast. Despite hailing from a high-income region, respondents gave the third-lowest institutional capacity ratings—only 11 percent found it to be 'adequate'. However, human resources availability appears relatively stronger. The interviewed experts shed light on the possible reasons for this: Federal programmes and funding mechanisms provide significant technical depth and professional expertise, but uneven staffing and resourcing at state and municipal levels lead to variable capacity across governance bodies. This reveals a critical implementation gap between national capability and local delivery.

Questionnaire responses for East Asia and the Pacific demonstrate the most positive outlook, with 31 percent of the respondents rating institutional capacity as 'adequate'. However, the interviewed experts noted that while in certain countries institutional frameworks and technical skills are relatively strong, high staff turnover, frequent rotations, and reliance on external contractors impede the continuity of resilience planning. This suggests that the apparent strength may mask operational vulnerabilities.
The Europe and Central Asia region shows interesting complexity: 55 percent of the respondents reported 'variable' institutional capacity, and 29 percent said it was 'limited'. The interviewed experts cautioned that despite the relatively strong frameworks and technical skills in some countries, high staff turnover, frequent rotations, and reliance on external contractors undermine long-term continuity planning. This demonstrates that technical capacity alone cannot overcome institutional fragmentation.

In Sub-Saharan Africa, while institutional capacity faces challenges—17 percent of the respondents perceived it as 'adequate' and 39 percent as 'limited'—the availability of human resources appears stronger than in the other regions. Interviews with the experts allowed for further contextualization, as they noted that while certain countries have emerging institutional frameworks and policies for infrastructure resilience, capacity is generally concentrated in the capital cities, and reliance on foreign contractors weakens long-term resilience. As an expert pointed out, "Most of [our] big projects are managed by foreigners, and when they pull out, we are left without the skills to maintain."

Questionnaire responses from the Middle East and North Africa region suggest strong institutional capacity overall: 31 percent of the respondents rated it as 'adequate', 34 percent as 'variable', and 35 percent as 'limited'. However, expert interviews and FGDs reveal sharp disparities. In certain countries, major urban centres benefit from strong agencies, progressive standards, and structured upskilling, while elsewhere, prolonged hiring freezes and low pay have left local authorities understaffed, dependent on external consultants, and lacking professionals with specialized skills for sustained resilience planning.





Adequate: Sufficient to implement resilience measures across ministries and agencies

Variable: Sufficient in some agencies but significant gaps in others

Limited: Insufficient to implement measures without substantial external support across ministries

Figure 10

Public sector's institutional capacity for implementing infrastructure resilience, by region

Source: Authors' analysis

Figure 11

Human resources availability in the public sector for implementing infrastructure resilience, by region

Source: Authors' analysis

Country income level analysis

Country income level analysis underscores these findings (**Figures 12 and 13**): In high- and upper-middle-income countries, public institutions often benefit from the presence of more advanced frameworks, progressive policies, and specialized agencies. Yet shortages of trained personnel at sub-national levels and uneven sectoral coverage mean that even strong national systems do not always translate into consistent local implementation. Expert interviews consistently highlight that local governments often lack the staff or financial resources to implement high-level policies while responsibilities are fragmented across ministries and levels of government. Priorities identified across these contexts emphasize strengthening local capacity and improving cross-sectoral coordination.

By contrast, in lower-middle- and low-income countries, challenges include weaker institutional frameworks and scarcity of staff. Ministries more often struggle to recruit or retain skilled professionals, leaving gaps in enforcement and donor-funded technical support. An expert highlighted that

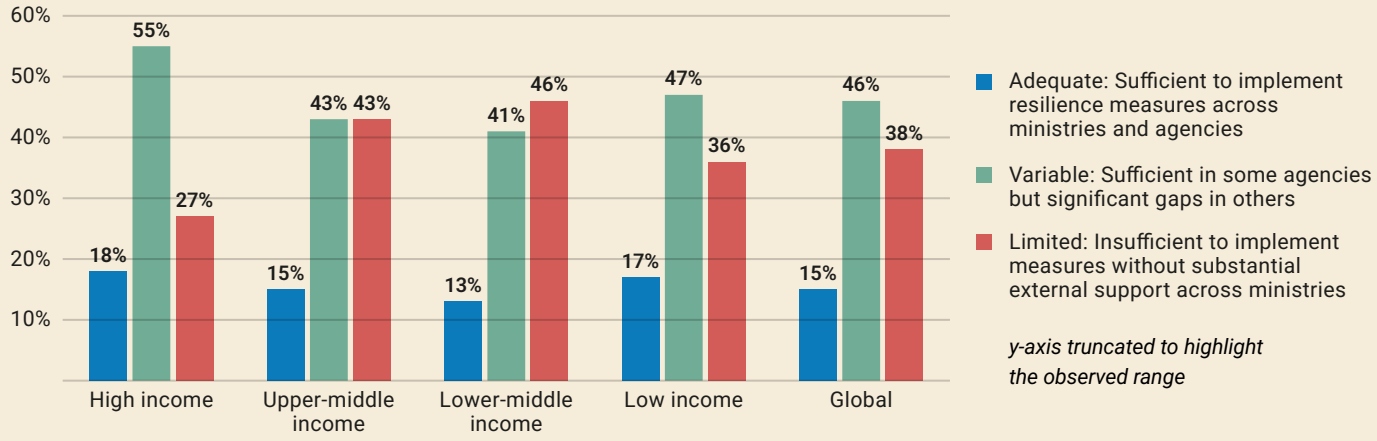


Figure 12

Public sector's institutional capacity for implementing infrastructure resilience, by country income level

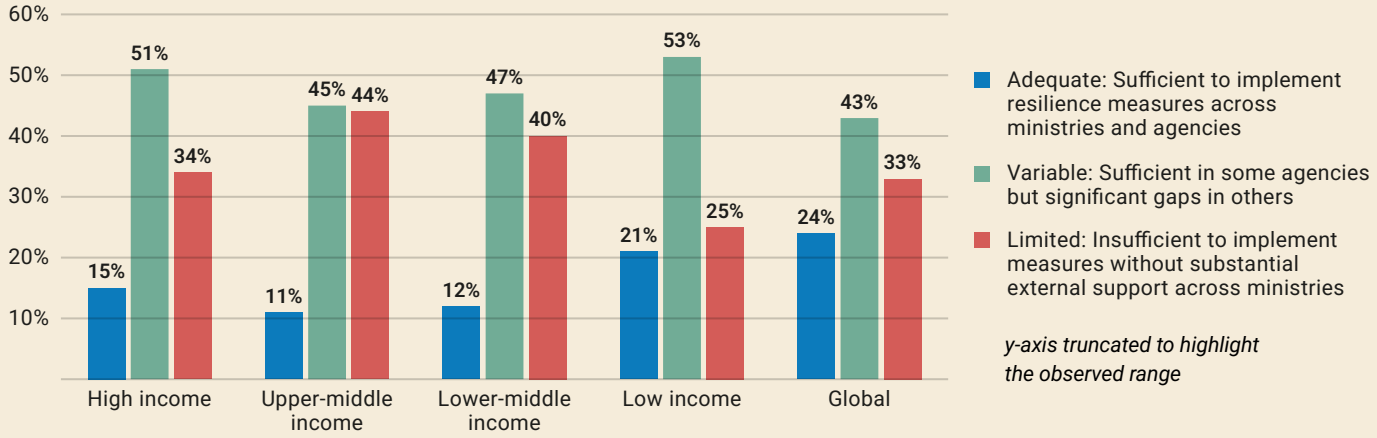
Source: Authors' analysis

"human resources are concentrated at central headquarters, leaving inadequate staffing at the local level for resilience tasks." Priorities in these contexts are improving technical capacity at sub-national levels, strengthening regulatory enforcement mechanisms and compliance monitoring, and expanding training and professional development.

Figure 13

Public sector's institutional capacity for implementing infrastructure resilience, by country income level

Source: Authors' analysis



Discussion

Comparative analysis shows that both public- and private-sector respondents consistently identified the same weaknesses. Across regions and country income levels, institutional capacity and human resources for infrastructure resilience were rarely seen as 'sufficient'—they appear to be strong in some ministries, agencies, or sectors but uneven elsewhere. Key challenges include fragmentation among agencies, difficulty retaining skilled staff, and gaps in technical expertise in government bodies, all of which hinder the translation of policy into practice. Without systemic reforms to strengthen coordination, build local staffing and technical capacity, and ensure continuity in governance, resilience strategies will remain aspirational, and national policies will fail to translate into locally delivered, resilient infrastructure.

It is also important to note that the concept of resilient infrastructure is interpreted variously depending on the context. The experts noted that many local practitioners and institutional workforces lack a shared practical understanding of how to operationalize resilience. While the term is widely recognized, it is often treated as a general aspiration rather than a set of concrete actions embedded throughout the infrastructure life cycle. This inconsistency contributes to the fragmented implementation of resilience policies and limits their effectiveness. Building a common baseline through clearer definitions, practical guidance, and targeted capacity-building is critical to align approaches and support the systematic incorporation of resilience into public infrastructure systems.

Box 2

Case study: The National Infrastructure and Service Transformation Authority, United Kingdom

The National Infrastructure and Service Transformation Authority (NISTA), launched in April 2025, represents a fundamental change in the United Kingdom's approach to infrastructure governance. NISTA consolidates strategic planning and project delivery within a single organization, with responsibility for advising the government on infrastructure investment priorities, delivery mechanisms, and long-term system improvements. NISTA operates as the central implementation body for the government's 10 Year Infrastructure Strategy, which prioritizes service reliability, system resilience, and sustained capital investment.

NISTA oversees resilience planning across the United Kingdom's £725 billion infrastructure investment pipeline. Key programmes include £7.9 billion allocated to flood defence improvements, an annual budget exceeding £10 billion for social infrastructure maintenance and renewal, and development of the National Infrastructure Spatial Tool, which coordinates planning decisions on climate adaptation, housing delivery, and energy system transitions. NISTA conducts systematic reviews of resilience standards for critical infrastructure sectors, water supply, energy networks, transport systems, and digital communications, identifying regulatory gaps and updating technical requirements to address climate risks.

The creation of NISTA addresses a recognized need for stronger institutional coordination between policy development, regulatory oversight, and delivery capacity. This structural reform acknowledges that infrastructure resilience requires not only technical solutions but also effective governance frameworks and coordinated action across government departments, regulatory bodies, and delivery organizations.

3.2 Private Sector's Technical Capacity and Availability of Human Resources

This section presents the results on technical capacity and human resources availability in the private sector for implementing infrastructure resilience. The private-sector stakeholders engaged in this study—including engineering firms, contractors, designers, and infrastructure operators—are the primary implementers of resilience strategies and therefore play a critical role in embedding resilience throughout the infrastructure life cycle. They help translate policy into practice, apply innovative designs and technologies, mobilize investment, and enforce compliance with resilience standards, thereby ensuring that infrastructure is sufficiently resilient to withstand shocks, adapt to emerging risks, and maintain essential services. Their technical skills and specialized expertise, as well as their skilled workforce, are essential enablers for delivering resilient infrastructure at scale.

The availability of skilled human resources is crucial, yet many regions face shortages of engineers and technical experts, particularly in climate-vulnerable areas, which hampers the consistent implementation of resilience measures (International Coalition for Sustainable Infrastructure, 2024).

KEY FINDING 2

Private-sector capacity is critical for implementing infrastructure resilience, yet technical expertise and human resources remain highly variable across regions and country income levels, with over half the respondents reporting uneven distribution. Experts highlighted that capacity is often concentrated in large firms and capital cities. While private-sector capacity generally exceeds the public sector's levels, competition over the limited number of specialists—particularly in lower-middle- and low-income countries—creates systemic gaps, pointing to the need for coordinated workforce development, capacity-building, and broader interventions across both sectors.

Global trends

The overall global results show that the private sector's capacity for infrastructure resilience, in terms of both technical expertise and human resources, is mostly seen as 'variable', with roughly half the participants choosing this option. This variability represents the dominant challenge, as resilience efforts depend heavily on which specific organizations are engaged in them rather than sector-wide capability. Out of the remaining participants, 29 percent perceived the private sector's technical capacity and human resources availability as 'adequate'.

When comparing sectors, respondents from the building sector and other infrastructure sectors show nearly identical patterns, with the option of adequacy chosen by slightly fewer professionals from other infrastructure sectors. The same is true when comparing across organization types, with the notable finding that the

private sector views itself slightly more positively—a third of the respondents selected the 'adequate' option versus a quarter of the public-sector respondents—although the dominant pattern of uneven distribution remains consistent.

When comparing results from countries with different levels of vulnerability to hazards, the pattern holds, with the private sector's technical capacity and human resources availability largely perceived as 'variable' rather than consistently strong or weak; only around a quarter of the respondents rated them as 'adequate' and a similar share as 'limited'. This consistency within the global results suggests that capacity challenges exist across sectoral and vulnerability boundaries, indicating the private sector's uneven and inconsistent capacity worldwide.

Country income level analysis

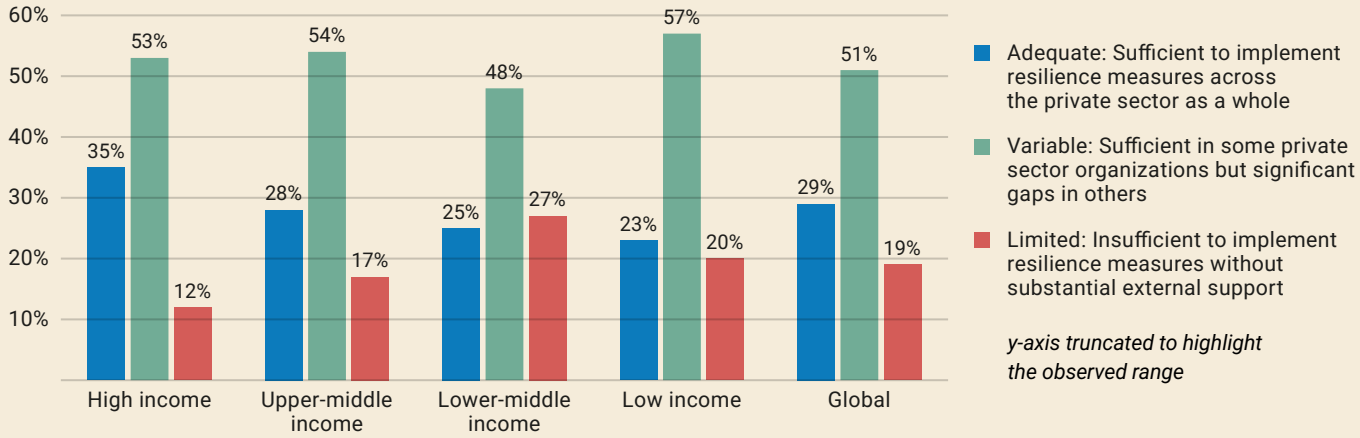
Income-level analysis highlights how economic development shapes, but does not fully determine, private-sector capacity in resilience (**Figures 14 and 15**). In high- and upper-middle-income countries, 53–54 percent of the respondents described the private sector's technical capacity, expertise, and human resources availability as 'variable'—strong in some organizations but with significant gaps in others. About a third of the respondents regarded capacity as 'adequate'—technical capacity and subject matter expertise 28–35 percent, human resources 25 percent.

In lower-middle- and low-income countries, especially, the data indicates a perception that the private sector's technical capacity and expertise are stronger than human resource availability. The majority of the respondents reported 'variable' (48–57 percent) or 'adequate' (23–25 percent) technical capacity and expertise, while only 20–21 percent considered human

Figure 14

Private sector's technical capacity and expertise for implementing infrastructure resilience, by country income level

Source: Authors' analysis



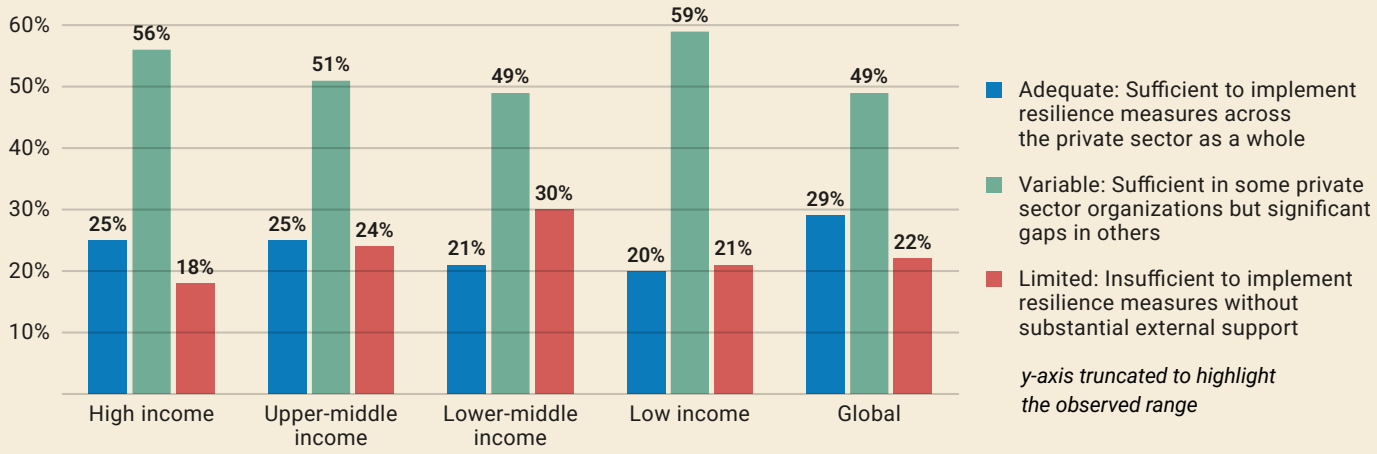


Figure 15

Human resources availability in the private sector for implementing infrastructure resilience, by country income level

Source: Authors' analysis

resources to be sufficient, with 49–59 percent noting variation. Interviews indicate that expertise—including advanced skills in engineering, risk modelling, insurance, and project delivery—is concentrated in a few large firms, industry associations, or international consultancies; local small and medium-sized enterprises (SMEs) face skill shortages, particularly outside economically strong regions and in hazard-prone areas. Competition for scarce specialists limits overall capacity, often forcing reliance on donor-funded contracts or external consultants. Resilience knowledge is often incorporated into projects, though in some sectors or regions it remains fragmented.

Regional analysis

Regional analysis helps to identify several interesting trends (**Figures 16 and 17**). In Latin America and the Caribbean, only 17 percent of the questionnaire respondents considered the private sector's human resources 'adequate', and 32 percent rated them as 'limited'—the highest percentage reporting limited resources among the regions. Interviews and FGDs confirmed that private-sector capacity is mixed: Some countries benefit from strong engineering traditions and firms capable of delivering major projects, while others continue to face significant gaps in technical expertise.

In Sub-Saharan Africa, 40 percent of the participants perceived human resources as 'adequate'—the highest among all the regions—but they reported that capacity is even more constrained. Expert interviews highlighted pockets of strong capacity, particularly in higher-income countries with established firms and professional associations. While pockets of strong engineering capacity exist, the overall landscape remains uneven. Across much of the region, limited technical education, shortages of practitioners with emerging skills, and heavy reliance on external actors leave overall capacity fragmented and unable to meet the growing infrastructure demands.

In Europe and Central Asia, 25 percent of the respondents viewed human resource availability as 'adequate', and 59 percent rated it as 'variable'. Expert interviews indicated that technical capacity was generally perceived as strong, supported by large operators and international consultancies. However, experts cautioned that sectoral silos and, in some cases, conservative industry cultures limit the incorporation of resilience into practice.

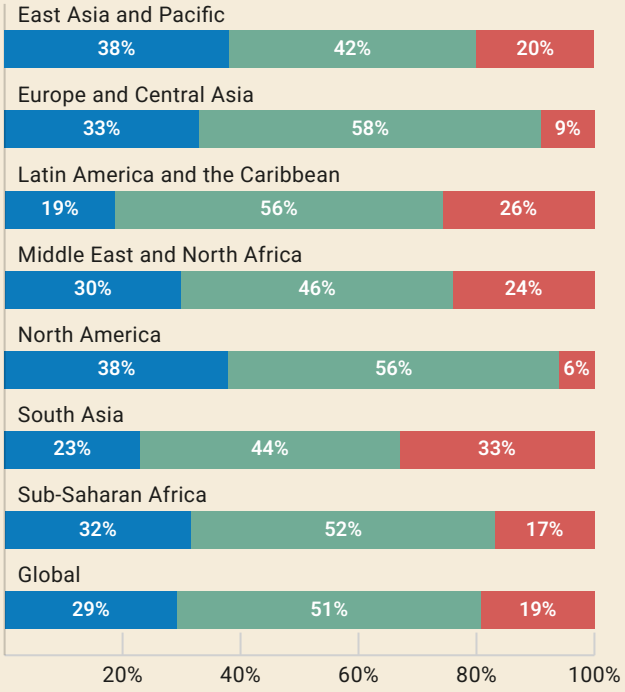


Figure 16

The private sector's technical capacity and expertise for implementing infrastructure resilience, by GIR 2023 region

Source: Authors' analysis

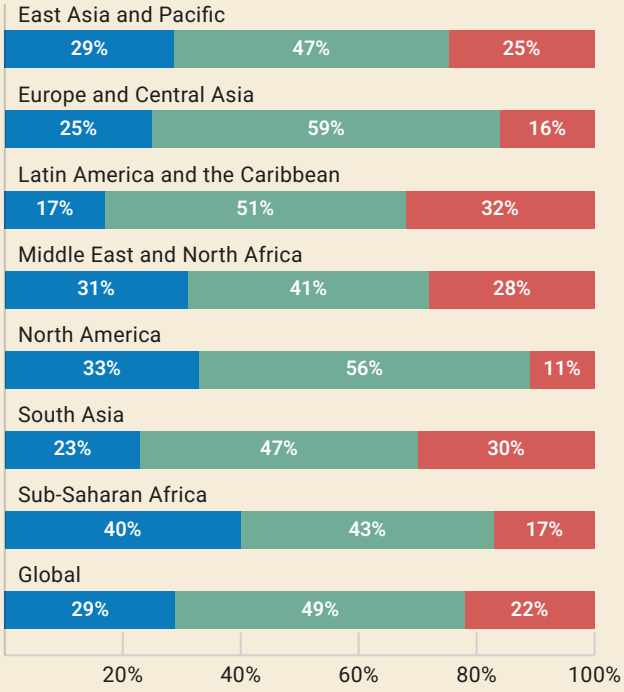


Figure 17

Human resources availability in the private sector for implementing infrastructure resilience, by GIR 2023 region

Source: Authors' analysis

In East Asia and South Asia, the patterns diverge. In East Asia and the Pacific, 29 percent of the respondents perceived human resource availability as 'adequate', while in South Asia, 30 percent considered it insufficient. Experts interviewed in East Asia and the Pacific viewed high-income countries in the region as benefitting from advanced technical bases and dynamic innovation hubs, while lower-income countries were seen to rely heavily on smaller consultancies that lack the scale to deliver systemic solutions. Experts from South Asia highlighted severe shortages of skilled professionals, which constrain the region's ability to integrate infrastructure resilience with planning significantly.

In North America, 33 percent of the respondents reported that human resources were 'adequate', and 56 percent stated that they were 'variable'. Expert insights support these findings, suggesting that while the private sector combines strong insurance, consulting, and engineering capacity, shortages in staffing and uneven workforce distribution leave some areas with far fewer resources than others.

In the Middle East and North Africa, questionnaire responses show a

mixed picture. While 30 percent of the respondents viewed the private sector's capacity as 'adequate', nearly half saw it as 'variable' and a quarter as 'limited'. Human resource availability was assessed less favourably, with only 31 percent viewing it as 'adequate' and the rest split between ratings of 'variable' and 'limited'. The interviewed experts and FGD participants noted strong technical foundations in traditional sectors such as construction, energy, and logistics, but resilience-specific skills and technologies remain underdeveloped. Although the region has a solid pool of technical professionals, persistent gaps in specialized expertise—especially in regional firms not based in larger cities—hinder progress.

Discussion

The widespread variability and uneven distribution of technical capacity and human resources in the private sector imply that resilience outcomes depend heavily on identifying and engaging capable organizations rather than relying on consistent sector-wide capacity. This unevenness creates fragmentation, with pockets of excellence alongside significant gaps. Skilled human resources are particularly critical, yet many regions face shortages of engineers and technical experts, especially in climate-vulnerable areas.

The interviewed experts and FGD participants highlighted several ways in which the private sector can drive the implementation of climate- and disaster-resilient infrastructure. Across geographies, its most prominent roles are providing technical expertise and innovation and mobilizing financing through co-investment and public–private partnerships (PPPs). Another vital area is regulatory standards and compliance, where the private sector can not only demonstrate leadership by meeting resilient construction requirements but also help close enforcement gaps by setting and promoting higher technical benchmarks. In many contexts, particularly in low- and lower-middle-income countries, private companies also play a crucial role in building local capacity, training SMEs, mentoring government agencies, and fostering the skills needed to sustain resilience over the long term.

Upskilling and continuous professional development are essential to help practitioners assess climate risks, apply resilience standards, and work across disciplines. By investing in interdisciplinary training and promoting technical excellence, the private sector can drive innovation, reduce life cycle risks, and deliver infrastructure that protects communities and economies. Achieving this requires coordinated workforce development, standardization of practices, and mechanisms to disseminate expertise across sectors rather than allowing it to remain concentrated in select organizations.

The interviewed experts and FGD participants consistently called for a shift in private-sector incentives, moving away from short-term cost-cutting towards long-term investments that prioritize resilience and operational sustainability. This mindset shift is key to unlocking the private sector's full potential—not just as contractors or financiers but also as strategic partners driving systemic resilience.

Cross-cutting analysis: Comparing public- and private-sector capacities

Significant differences emerge in the capacity challenges faced by the public and private sectors. The public sector's constraints are rooted in institutional fragmentation, gaps between policy design and implementation, and persistent difficulties in translating national frameworks into effective local action. In contrast, the private sector's challenges are shaped by market dynamics, with expertise concentrated in a small number of large firms, intense competition for a limited pool of specialists, and reliance on external funding.

Overall, the private sector is perceived to possess higher capacity, with over 30 percent of the respondents in some regions reporting adequacy compared with 15 percent for public institutions. This suggests that market mechanisms can effectively concentrate expertise where it is economically viable but often leave significant gaps elsewhere.

Regional patterns reveal important nuances. In areas where public capacity is weak but private expertise is relatively strong, such as local hubs in Sub-Saharan Africa, PPPs could play a vital role in bridging the gap. Conversely, where both sectors face constraints, as seen in Latin America and the Caribbean, systemic interventions and long-term institutional reforms are required.

Finally, competition between sectors for the same scarce specialists, which is particularly acute in lower-income countries, highlights the need for integrated capacity-building strategies that consider the interdependencies between public and private actors rather than treating them as isolated entities.

3.3 Retrofitting Programmes

Retrofitting existing infrastructure becomes critical as assets age and the hazard and risk landscape evolves with climate change, urbanization, and shifting socio-economic pressures. A proactive retrofitting programme strengthens the resilience of these assets, extending their service life, improving safety, and reducing long-term maintenance and replacement costs. Many infrastructure systems, especially in low- and middle-income countries, were not designed with current or future climate scenarios in mind, making them vulnerable to service disruption and failure during extreme events.

Retrofitting interventions must be guided by robust vulnerability assessments that consider site-specific hazard exposure and asset criticality. Interventions may include structural reinforcements, elevation, drainage improvements, or the integration of NbS to buffer impacts. The process must align with updated resilience standards and codes and should be supported by targeted financing mechanisms and risk-informed planning. Retrofitting is particularly crucial for infrastructure located in densely populated urban areas, where replacement may be unfeasible due to space or cost constraints or the risk of disruption. When it is strategically implemented, retrofitting not only improves resilience but also enhances inclusivity, access, and equity by prioritizing the protection of vulnerable communities.

Global trends

Globally, only about 15 percent of the respondents reported the existence of comprehensive, nationwide retrofitting programmes. In contrast, around 42 percent described such efforts as sporadic and typically reactive—launched in response to a disaster—or limited to specific hazards. Over 20 percent said that retrofitting programmes are rare or absent.

This fragmentation pattern is remarkably consistent across sectors and stakeholders. In both the building sector and other infrastructure sectors, the majority of respondents noted sporadic implementation of retrofitting programmes. The same is true for public- and private-sector perspectives. The reporting of mostly sporadic, project-based retrofitting rather than systematic programmes, combined with around a quarter of the respondents stating that retrofitting is rare or non-existent, reveals that substantial portions of existing infrastructure receive no resilience upgrades at all. Even where retrofitting exists, 22 percent of the total respondents said that it was a targeted initiative—confined to high-priority assets or specific hazard-prone sectors—rather than a programme addressing systemic vulnerability.

KEY FINDING 3

Retrofitting remains fragmented, with nationwide programmes being the exception rather than the norm. Globally, just 15 percent of the respondents reported comprehensive national initiatives, while the majority highlighted sporadic projects that were most often a response to recent disasters or hazard-specific risks rather than systematic policy. Where retrofitting initiatives do exist, they are typically confined to particular assets or sectors; in many cases, they were perceived to be rare or non-existent. This piecemeal approach leaves major gaps in resilience, particularly as ageing assets face more severe climate and disaster risks. Common barriers across all geographical regions include financing constraints, shortages of technical expertise, and competing pressures to expand basic infrastructure.

Country income level analysis

Country income level analysis highlights some counterintuitive patterns (**Figure 18**). The highest proportion of respondents reporting comprehensive nationwide programmes was from low-income countries (24 percent), although expert interviews indicate that these are typically donor-supported pilot projects with limited scope. In contrast, in high-income countries, only 14 percent of the respondents reported comprehensive coverage; 34 percent mentioned targeted initiatives, and 42 percent described projects as sporadic. Experts noted that even established programmes targeting critical infrastructure—such as schools, hospitals, water systems, and transportation networks—leave smaller assets and secondary infrastructure unaddressed, with retrofits often confined to routine maintenance rather than proactive resilience upgrades.

Responses from upper-middle-income countries show significant gaps, with only 12 percent reporting nationwide programmes and 46 percent pointing to sporadic projects. Expert interviews reveal that governments have not established nationwide frameworks

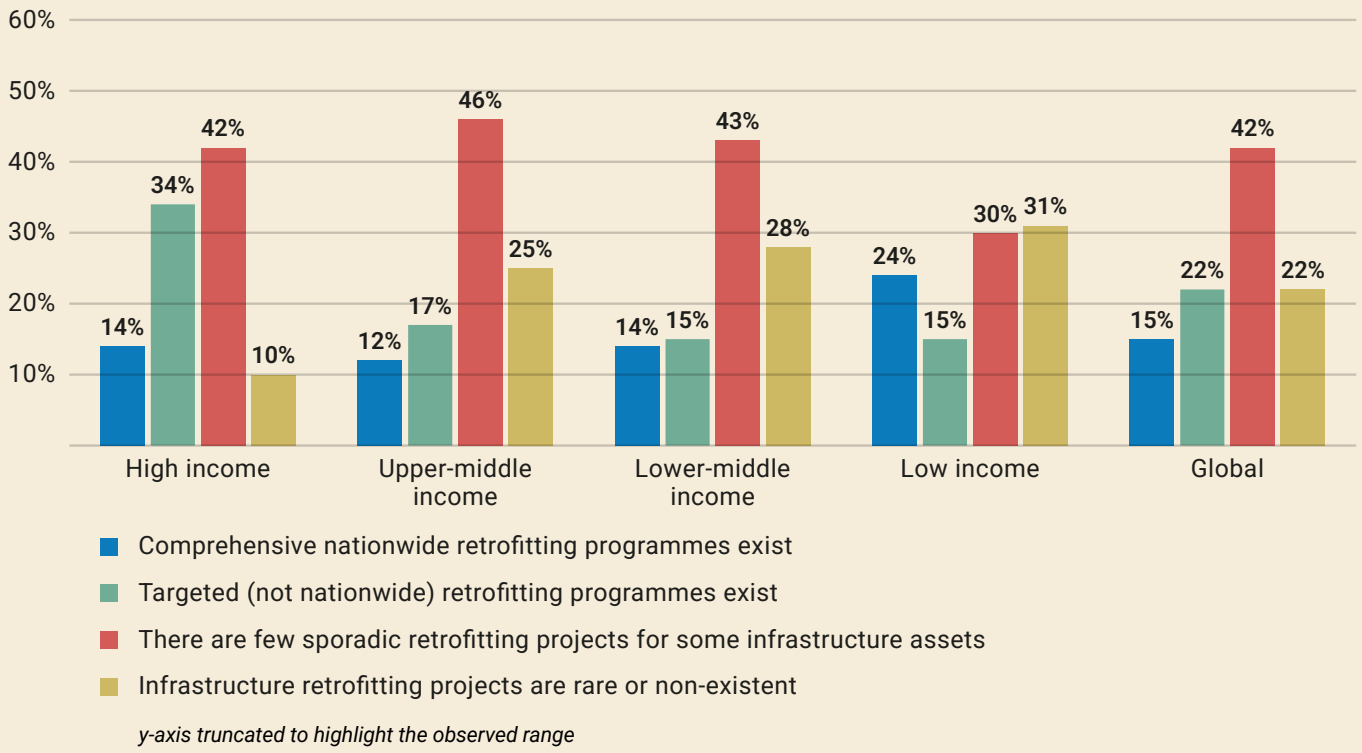


Figure 18

Retrofitting programmes, by country income level

Source: Authors' analysis

in many contexts, which means that retrofitting remains ad hoc or confined to maintenance activities. Where more structured programmes exist, perceptions show that they tend to be sectoral and often rely heavily on donor funding or international partnerships rather than domestic financing. Similar challenges were identified by respondents from lower-middle-income countries, with 14 percent reporting comprehensive programmes and 43 percent noting sporadic implementation. In these countries, capacity is often concentrated in capitals or large-scale projects, technical expertise is limited, and attention is mostly focused on new construction rather than upgrading existing infrastructure.

Box 3

Case study: Istanbul Seismic Risk Mitigation and Emergency Preparedness Project, Türkiye

The Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP), launched in 2006, is a flagship World Bank–backed initiative focused on strengthening Istanbul's response to devastating earthquakes (Global Facility for Disaster Reduction and Recovery, 2015). Through investments totalling around $1.5 billioncluding $550 million in World Bank financing—the project has retrofitted or reconstructed over 1,086 public buildings, including schools and hospitals serving more than 1.1 million students and 8.7 million patients, respectively, annually.

Beyond physical upgrades, ISMEP pioneered a holistic approach, integrating public awareness campaigns, disaster volunteer programmes, upgrades to emergency communication systems, and training for over 3,600 civil engineers in seismic retrofitting standards. The project remains one of the largest urban seismic retrofitting programmes globally and is frequently cited as a model for other earthquake-prone cities.

Regional analysis

Regional variations in retrofitting implementation (**Figure 19**) reveal distinct patterns shaped by economic development, hazard exposure, and policy priorities.

Responses from Latin America and the Caribbean show the most limited progress on retrofitting globally, with only 8 percent of the respondents reporting comprehensive programmes and 56 percent describing projects as sporadic. Expert interviews suggest this is because governments prioritize new infrastructure or post-disaster reconstruction over proactive, systematic upgrading. The interviewed experts noted that retrofits tend to be incidental to maintenance or reconstruction rather than part of resilience frameworks, occurring as isolated upgrades or donor-supported rehabilitation of specific assets.

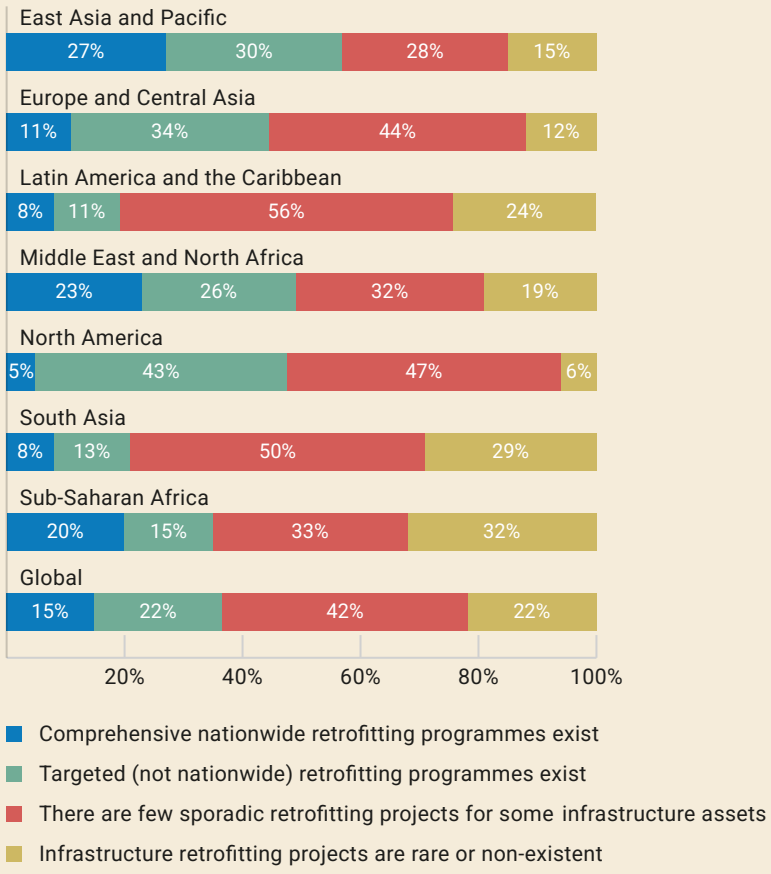
The Europe and Central Asia region presents an interesting contrast: Although 44 percent of the respondents reported sporadic projects, some countries have implemented large-scale upgrades. Expert interviews reveal mixed approaches. Some higher-income states implement systematic retrofits of critical infrastructure—dykes, locks, and bridges, and mandated retrofits in PPP contracts—while others rely heavily on external funding. It was reported that national seismic prevention plans for schools and hospitals often exist in earthquake-prone areas, though many countries focus efforts on energy efficiency retrofits rather than comprehensive resilience upgrading.

In the East Asia and Pacific region, results show the strongest reporting of retrofitting activities, with 27 percent of the respondents identifying nationwide programmes and 30 percent targeted programmes. The interviewed experts from high-income countries in the region cited examples such as mandated comprehensive seismic retrofitting,

Figure 19

Retrofitting programmes, by GIR 2023 region

Source: Authors' analysis



extensive housing retrofits, coastal retrofitting, and utilities upgrades supported by dedicated agencies and stable financing. In contrast, middle- and lower-income countries limit retrofitting to more reactive, post-disaster improvements without systematic frameworks, such as small-scale road retrofitting along flood-prone corridors.

In North America, the questionnaire responses revealed surprisingly limited coverage, with only 5 percent reporting nationwide programmes, although 43 percent identified targeted initiatives. Expert interviews indicated that retrofitting programmes exist and have proven effective when applied but implementation remains limited and is vulnerable to funding cuts.

Sub-Saharan Africa presents mixed results, with 20 percent of the respondents reporting nationwide programmes, 33 percent describing projects as sporadic, and 32 percent considering them rare. The interviewed experts pointed out that upper-middle-income countries have piloted targeted programmes—such as coastal protection and road systems with retrofit elements—typically with donor funding but without national scaling. Similarly, in lower-income settings, examples of donor-funded small-scale interventions include slope stabilization and wetland rehabilitation. However, capacity shortages, funding gaps, and the pressure to expand basic infrastructure outweigh investment in retrofitting.

Results from South Asia highlight specific challenges, with only 8 percent of the respondents reporting comprehensive programmes, while 50 percent described projects as sporadic. Expert interviews point out that structured programmes focus on specific hazards, such as large-scale seismic retrofits in earthquake-prone areas or road infrastructure following flood damage. Beyond these flagship projects, most resources target new construction rather than existing infrastructure upgrades.

Finally, the Middle East and North Africa region occupies a middle position, with 23 percent of the respondents citing nationwide initiatives and 26 percent targeted programmes, though 32 percent identified sporadic projects, suggesting pockets of advancement within overall underdeveloped systematic approaches.

These regional patterns reveal that retrofitting implementation correlates more strongly with institutional capacity and policy priorities than with country income levels, with even wealthy regions showing significant gaps when systematic frameworks are absent.

Discussion

Across income levels, regions, sectors, and stakeholders, implementation of retrofitting programmes was found to be fragmented, representing a critical vulnerability in infrastructure resilience on a global scale. Such systematic under-investment in upgrading existing assets means that infrastructure built for past climate conditions continues to operate without adaptation to current and future risks.

The universal nature of retrofitting challenges transcends economic boundaries. While financing constraints affect all income groups, the specific barriers vary: High-income countries struggle with competing priorities for ageing infrastructure and regulatory hurdles, middle-income countries face technical capacity shortages and institutional fragmentation, while low-income countries must balance retrofitting against expanding basic service coverage. Moreover, placing the full financial burden of retrofitting buildings and infrastructure solely on property owners and individual communities is not feasible, given that many stakeholders, including insurance

companies and the mortgage industry, benefit from retrofitting for resilience (National Institute of Building Sciences, 2025). These distinct challenges require tailored approaches rather than universal solutions.

The predominance of reactive, post-disaster retrofitting reinforces a costly and dangerous cycle. Without systematic, pre-emptive upgrades, infrastructure failures during extreme events will prompt emergency repairs that rarely include comprehensive resilience measures. This 'build back the same' approach not only perpetuates vulnerability but also squanders opportunities for more cost-effective risk reduction, exposing communities to repeated disruption and economic loss.

This persistent gap between recognized needs and implementation reflects deep-seated institutional weaknesses. Although the value of retrofitting for resilience is widely acknowledged, the absence of dedicated funding, clear mandates, specialized technical expertise, and institutional champions means that the onus is often diffused and even neglected. This orphaned status within infrastructure governance leads to fragmentation, under-investment, and missed opportunities to protect lives, livelihoods, and critical services.

3.4 Coordination Capacity for Hazard Mitigation, Disaster Preparedness, and Disaster Response and Recovery

Infrastructure systems are interdependent and deeply embedded within community safety and continuity practices. Structured coordination improves risk identification, emergency planning, and recovery prioritization, ultimately reducing disruptions and accelerating recovery. For effective disaster preparedness and mitigation, close collaboration between the concerned stakeholders is essential to ensure that climate and hazard risk assessments inform infrastructure design, siting, and retrofitting. DRM agencies provide hazard data and early-warning insights, while infrastructure actors translate these into technical standards and investments. During the response phase, resilient infrastructure plays a life-saving role in enabling evacuation, emergency logistics, and health care access. Coordination ensures that emergency protocols consider the infrastructure system's limitations and redundancies. In recovery, infrastructure-related organizations must work with DRM authorities to rebuild in ways that are safer and more resilient than before. This whole-of-system coordination is what eventually turns resilience strategies into real-world outcomes.

KEY FINDING 4

Coordination between DRM agencies and infrastructure-related organizations remains reactive and fragmented globally. While crisis response mobilizes institutional collaboration somewhat more effectively, proactive mitigation and preparedness coordination are consistently weak across all regions. Political discontinuity disrupts recovery programmes, municipalities lack the capacity to implement national policies, and recovery rarely includes resilience considerations, perpetuating vulnerability cycles despite the presence of functional emergency response mechanisms.

Global trends

Globally, coordination between infrastructure-related organizations and DRM agencies was widely described as fragmented and inconsistent, with variability being the dominant pattern across all phases of the disaster cycle. Expert interviews reinforced these findings, highlighting that while coordination mechanisms exist in many contexts, they are often inconsistently applied or limited to specific events rather than embedded in routine planning.

Survey data shows that strong coordination is rare. In the case of hazard mitigation, only 15 percent of the respondents reported 'consistently strong' coordination, while 49 percent described it as 'variable' and 36 percent as 'consistently weak'. Preparedness presents a similar imbalance, with 15 percent of the respondents noting strong coordination, about half of them 'variable', and one-third 'consistently weak'. Response and recovery were perceived somewhat more positively, with 21 percent of the respondents indicating strong coordination, a majority of them 'variable', and 26 percent weak.

These patterns are consistent across organization types. For example, just around one in six public- and private-sector respondents, and a tenth from academia, non-profits, and financial institutions perceived strong coordination in hazard mitigation.

Expert interviews emphasized that while coordination often improves during crises, these gains are rarely sustained. This reflects a reactive cycle, wherein collaboration strengthens temporarily in response and recovery but fails to translate into systematic risk reduction or resilient reconstruction. Overall, the findings suggest that across all vulnerability contexts, coordination remains uneven and episodic, with only modest improvements during the disaster response and recovery phases.

Country income level analysis

Coordination between infrastructure-related organizations and DRM agencies shows a dominant pattern of variability across all country income levels (**Figures 20–22**), with 26–36 percent of the respondents highlighting consistently weak collaboration This variability reflects differences in underlying capacity and systemic challenges.

In high-income countries, 56 percent of the respondents reported variability in coordination for hazard mitigation, and only 18 percent described it as 'consistently strong'. Expert interviews reveal that although legal frameworks, emergency protocols, and technical capacity exist, implementation is uneven. Preparedness can be improved with hazard maps, early-warning systems, and centralized commissions, while response mechanisms will function effectively if there are clear restoration protocols. Recovery, however, remains fragmented and is often reliant on private actors with weak systemic coordination and slow bureaucratic processes.

In upper-middle-income countries, questionnaire responses show greater dysfunction, with 37 percent reporting 'consistently weak' coordination in mitigation measures—the highest weakness rating across income groups. The interviewed experts noted that while legal platforms and emergency commissions exist, they rarely integrate infrastructure planning with recovery procedures. Response improves during crises, yet recovery suffers from limited technical expertise, weak municipal capacity, and political turnover. Moreover, programmes often rebuild infrastructure as before, without incorporating resilience.

Respondents from lower-middle-income countries reported the most severe challenges, with 46 percent describing coordination as 'consistently weak' and only 10 percent as strong—the lowest adequacy rating globally. The interviewed experts noted that agencies worked in

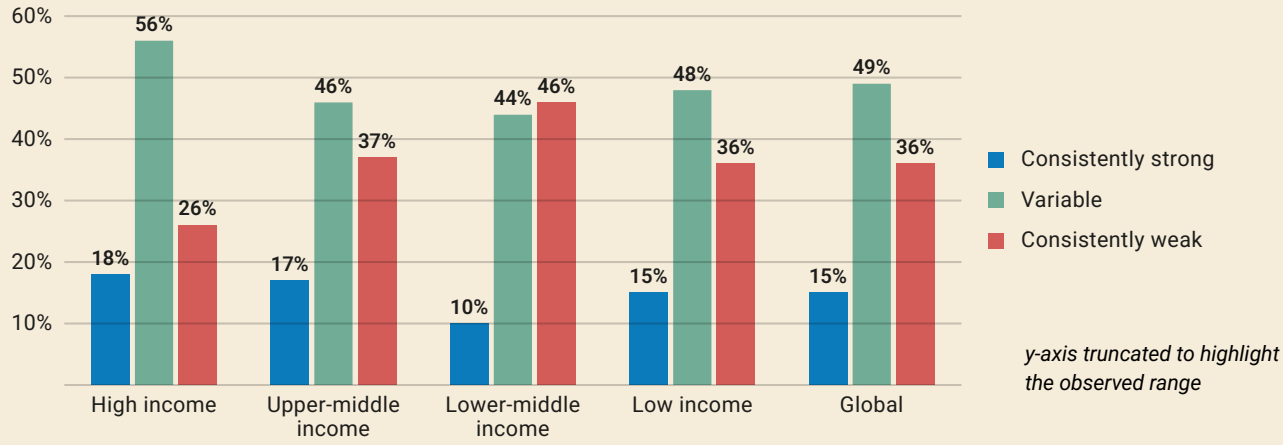


Figure 20

DRM coordination and hazard mitigation, by country income level

Source: Authors' analysis

isolation in maintaining preparedness. Response can become stronger through mobilization of security forces and international partners, but recovery suffers in the absence of clear coordination protocols.

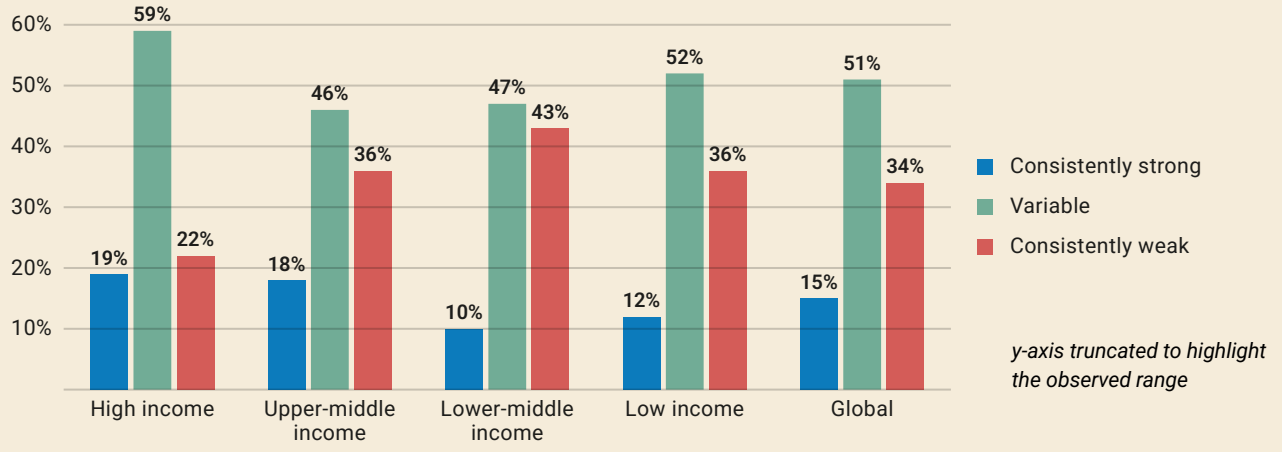
In low-income countries, 48 percent of the respondents reported variability in coordination, with 36 percent describing it as weak. The interviewed experts noted that recovery systems were largely reactive with minimal preparedness, but functional response was effective due to the rapid mobilization of police and army personnel, contractors, and NGOs.

Across all responses, preparedness was perceived to be the weakest, with 59 percent of the respondents from high-income countries and 46 percent from upper-middle-income countries reporting 'variable' coordination. Response showed modest improvement, with 29 percent of the respondents from high-income countries reporting strong coordination. Recovery, however, was considered fragmented across all contexts. In lower-

Figure 21

DRM coordination and disaster preparedness, by country income level

Source: Authors' analysis



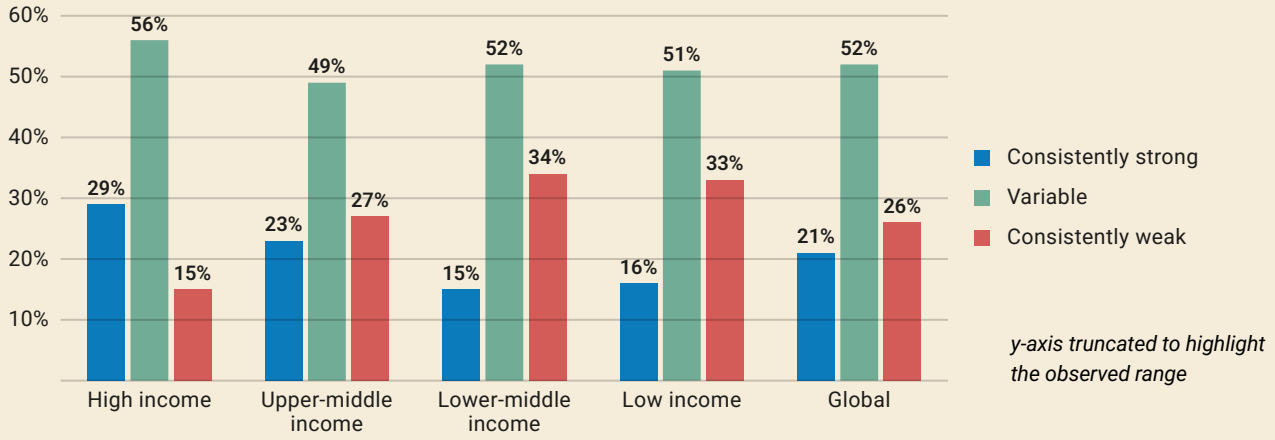


Figure 22

DRM coordination and disaster response and recovery, by country income level

Source: Authors' analysis

and middle-income countries, institutional and resource constraints limit sustained collaboration, resulting in reactive reconstruction that prioritizes speed over resilience.

The overall progression from weak preparedness to stronger response but fragmented recovery depicts a reactive cycle, where coordination improves during crises but fails to translate into systematic risk reduction or resilient reconstruction. As one expert noted, "Coordination for response and recovery has improved, but preparedness still suffers from conflicting priorities."

Regional analysis

Regional patterns (**Figures 23–25**) reveal distinct coordination challenges shaped by geography, hazard exposure, and institutional traditions. Respondents from East Asia and the Pacific reported the strongest coordination, with 38 percent perceiving coordination in mitigation measures as 'consistently strong' and 47 percent noting the same for response and recovery—the highest share among all the regions. Expert interviews attribute this to well-developed systems in high-income settings, including hazard maps, cross-ministry steering groups, and protocols established after major disasters. There are still gaps in recovery mechanisms, particularly in rural areas, where reconstruction includes resilience upgrades rather than just like-for-like replacements. In lower-income contexts, siloed agencies and the absence of recovery planning undermine preparedness, though community-led programmes—such as cyclone preparedness initiatives—sometimes strengthen response.

The share of respondents from Latin America and the Caribbean reporting weak coordination is concerning: Only 10 percent rated hazard mitigation coordination as 'consistently strong', while 39 percent considered it 'consistently weak'. The interviewed experts noted that though frameworks often exist, they are poorly integrated with infrastructure planning; there is limited risk assessment during planning; and ministries are unaware of each other's disaster management plans. While emergency commissions and multi-agency platforms improve coordination during response, recovery typically focuses on reconstruction without considering resilience. Further, municipalities lack technical capacity, and projects are abandoned after a political transition.

A high proportion of respondents from the Europe and Central Asia region reported variability in coordination—59 percent for disaster preparedness and 61 percent

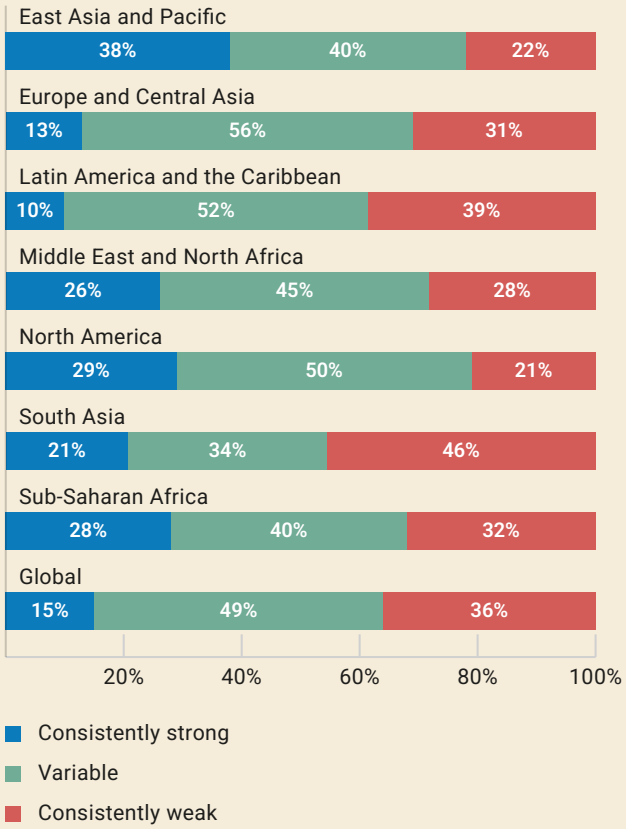


Figure 23

DRM coordination and hazard mitigation, by country income level

Source: Authors' analysis

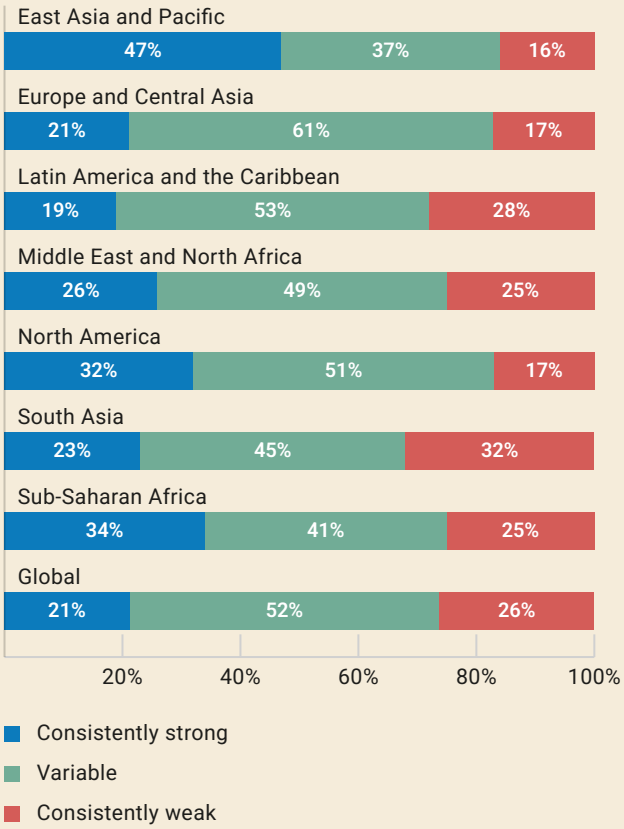


Figure 24

DRM coordination and disaster response and recovery, by region

Source: Authors' analysis

for disaster response and recovery. Relatively fewer responses indicated strong coordination (13 percent for preparedness). The interviewed experts suggested that the strong preparedness and response seen in high-income settings were supported by legal frameworks, structured training, multi-agency exercises, and mature early-warning systems. Recovery remains weak and fragmented across ministries. Bureaucratic hurdles and limited planning lead to delays in execution. While some countries invest in systematic reconstruction, others rely on external funding or private actors.

In Sub-Saharan Africa, questionnaire responses indicated mixed patterns, with 28 percent reporting strong mitigation coordination and 32 percent weak. Expert interviews highlighted a highly variable system: Some regions are supported by national DRM committees, but many agencies operate in silos. Emergency response functions well through the rapid mobilization of police and army units and contractors. Recovery, however, remains reactive and focused on replacement rather than resilience, with protocols poorly aligned with long-term objectives.

Respondents from South Asia reported the greatest coordination challenges, with 46 percent perceiving mitigation coordination as 'consistently weak'. The interviewed experts confirmed that agencies often operate in isolation with no recovery planning, although community-led initiatives provide some response capacity.

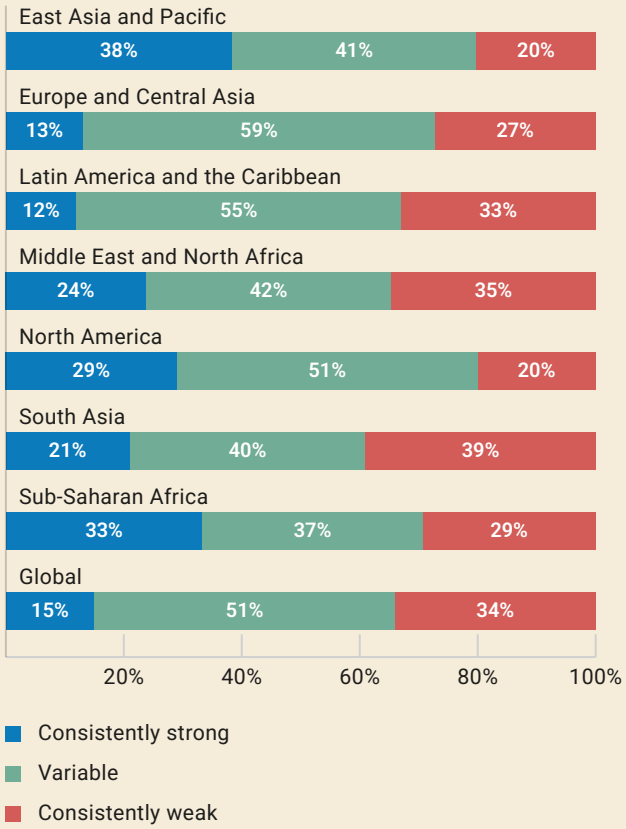


Figure 25

DRM coordination and disaster preparedness, by region

Source: Authors' analysis

Respondents from North America noted relatively strong coordination, with 29 percent rating mitigation measures as consistently strongly coordinated. The interviewed experts noted well-established frameworks, hazard mitigation programmes, and effective mutual aid during response. Yet recovery remains inconsistent, heavily reliant on local capacity, and often reactive, with 'build back better' principles applied unevenly across jurisdictions.

Respondents from the Middle East and North Africa reported balanced but fragmented coordination. Expert interviews highlight weak systems due to overlapping mandates, inconsistent multi-agency drills, and multiple codes and standards with minimal resilience enforcement. Recovery remains fragmented, sector-specific, and poorly integrated.

Discussion

The consistent finding across regions and country income levels that disaster response and recovery involve stronger coordination than mitigation or preparedness reveals a fundamental challenge. Visible crises mobilize institutional collaboration more effectively than proactive risk reduction. Expert interviews consistently confirm this pattern, with response mechanisms functioning well even where preparedness remains weak. Yet recovery often fails to incorporate resilience considerations into reconstruction.

Political continuity emerges from the interviews as a critical factor across multiple contexts, with projects being abandoned after a political transition and recovery programmes disrupted by electoral cycles. The gap between national frameworks and local implementation capacity occurs consistently, as municipalities lack the resources and expertise to maintain or upgrade infrastructure, even when national policies mandate resilience integration.

These findings indicate that effective coordination involves more than establishing institutional structures. Success requires sustained funding, technical capacity at all governance levels, political continuity, and systematic integration of DRM with infrastructure planning throughout the project's life cycle. Effective DRM will yield a triple dividend: economic stability, enhanced resilience, and increased private-sector investments and opportunities (United Nations Office for Disaster Risk Reduction [UNDRR], 2025). Without addressing these fundamental requirements, coordination will remain reactive and fragmented, hindering the translation of resilience policies into resilient infrastructure systems.

Box 4

Case study: Strengthening governance for resilience: Chile's SENAPRED/ SINAPRED

Chile offers a strong example of inter-agency coordination that integrates DRM with climate change adaptation. Despite high climate and disaster vulnerability, the country has shown notable progress in building an institutional framework that prioritizes resilience. The 2021 reform creating the National System for Disaster Prevention and Response (SINAPRED) and the National Service for Disaster Prevention and Response (SENAPRED) represents a major step in strengthening governance (UNDRR & CDRI, 2025). It shifts the focus from emergency response to a systemic, multi-sectoral, and multi-level approach that emphasizes prevention, coordination, and proactive risk management. SENAPRED provides technical support and mobilizes resources, while SINAPRED ensures cross-sectoral articulation through the full disaster cycle—that is, mitigation, preparedness, response, and recovery.

Complementary reforms, including the Climate Change Framework Law (June 2022), the updated National Land Use Planning Policy, and new instruments led by the Ministry of Public Works and Ministry of Housing and Urban Planning, and other agencies, expand capacities for risk prevention, territorial planning, and long-term infrastructure design under different climate scenarios. These reforms are recent and can encounter challenges, including fragmented infrastructure governance, limited oversight, and financing gaps, but they mark a decisive shift towards institutionalized, cross-sectoral collaboration.

Chile's recent Roadmap for Infrastructure Resilience, developed using the UNDRR and CDRI's Global Methodology for Infrastructure Resilience, underscores this governance approach as a cornerstone for long-term resilience.

3.5 Existence and Enforcement of National Regulations, Codes, and Standards

Regulations, building codes, and technical standards provide the baseline requirements for how infrastructure should be planned, designed, constructed, and maintained to withstand current and future hazards. As climate and disaster risks intensify, incorporating resilience into these instruments is essential to avoid locking in systemic vulnerabilities across infrastructure systems. Building codes and standards guide material selection, structural design, site placement, and operational performance to ensure that assets can endure shocks such as floods, earthquakes, and extreme heat (World Bank, 2024). However, many existing codes are outdated, lack climate considerations, or are poorly enforced, especially in low- and middle-income countries. Regulatory frameworks play a critical role in mandating risk assessments and resilience criteria at each stage of the infrastructure life cycle. When linked with procurement policies and performance incentives, regulations can drive innovation and accountability across both public and private sectors (American Society of Civil Engineers, 2025).

KEY FINDING 5

The global perception of regulations, codes, and standards is that despite their widespread existence they have limited adequacy. While around 80 percent of the respondents acknowledged that regulations, codes, and standards exist, only 22 percent said they adequately addressed infrastructure resilience and current hazard realities. Enforcement remains systematically inadequate, with fewer than one in five respondents reporting robust enforcement. Where they exist, enforcement mechanisms tend to focus on large projects but neglect local construction. Municipalities lack the resources, staff, and technical capacity to implement and enforce standards effectively.

Global trends

The global perspective on regulations, codes, and standards is that they have limited adequacy despite their widespread existence. While around 80 percent of the respondents reported that regulations, codes, and standards for infrastructure exist, only 22 percent believed they adequately address resilience and current hazard realities. Most of the respondents viewed these regulations as outdated, incomplete, or misaligned—with similar assessments across government and private-sector stakeholders—and perceived consistent gaps in the standards for both buildings and infrastructure.

Enforcement emerges as an even greater challenge than regulatory adequacy. Fewer than one in five respondents reported robust enforcement with third-party verification and penalties, while the majority described systems that either focus exclusively on large-scale national projects or have severely limited inspection capacity. Approximately one-third of the respondents indicated that enforcement mechanisms, where they exist, lack the resources and reach needed for effective oversight. This creates a situation where regulations exist primarily on paper and do not translate into resilient infrastructure on the ground.

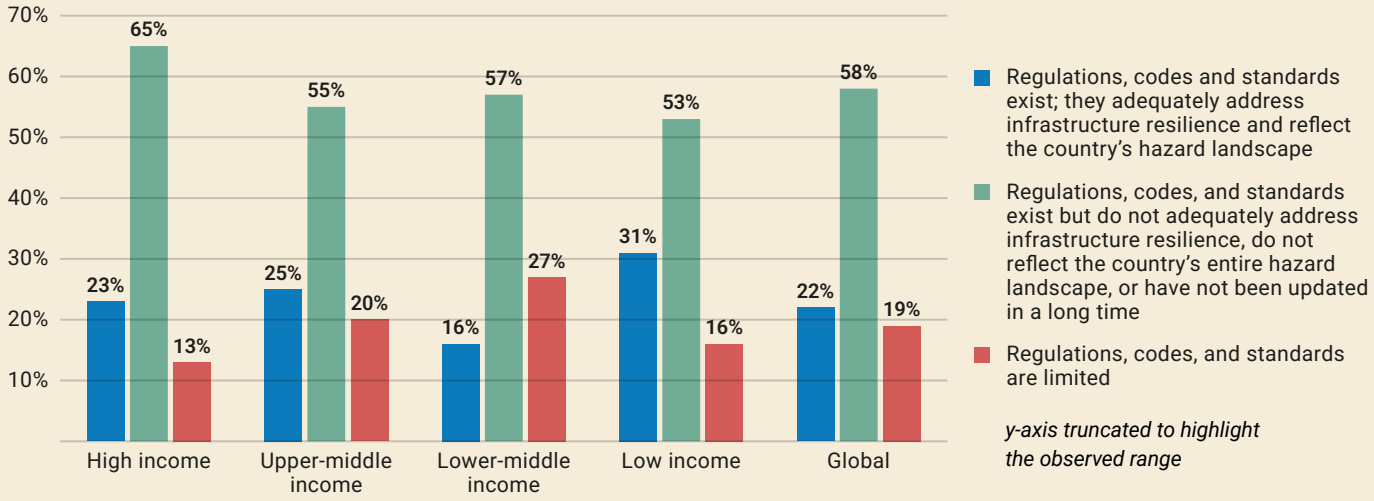


Figure 26

Regulations, codes, and standards, by country income level

Source: Authors' analysis

When comparing findings across countries with varying vulnerability to hazards, respondents from all countries viewed regulations for infrastructure resilience as mostly inadequate and poorly enforced. In countries with high vulnerability, only around a fifth of the respondents saw regulations as adequate; the majority noted that they are outdated or incomplete, with weak enforcement. In moderate-vulnerability countries, a similar share reported adequate regulations, but around an eighth noted strong enforcement. Respondents in low-vulnerability countries were slightly more optimistic, as a quarter perceived that regulations were adequate and a fifth claimed they had strong enforcement. Even where frameworks exist, coverage and implementation remain weak everywhere, especially in higher-vulnerability countries.

The consistency of these findings across different stakeholder perspectives strengthens their validity. Respondents across organization types exhibited nearly identical patterns in their assessments, suggesting that these do not indicate perception bias but, rather, reveal genuine systemic challenges. Similarly, stakeholders from the building sector and other infrastructure sectors reported comparable inadequacies, indicating that regulatory gaps are not sector-specific but represent a fundamental weakness in codes and standards due to the absence of resilience requirements.

Country income level analysis

The analysis by income groups (**Figures 26 and 27**) supports these findings. Between 53 and 65 percent of the respondents across every income category reported that regulations exist but are outdated, incomplete, or not fully aligned with hazard realities.

In high-income countries, only 23 percent of the respondents believed that regulations are fit for purpose. Expert interviews provide critical context for this finding: While codes and standards are comprehensive and widely established—covering building, transport, water, and energy systems—most of them still rely heavily on historical hazard data rather than forward-looking climate scenarios. Some jurisdictions have begun incorporating climate projections into design criteria—examples include rainfall and run-off guidelines, climate-informed building and fire codes, dyke design based on climate projections, and climate risk mapping applied in planning. However, these remain exceptions, as most standards for seismic or hydrological design use outdated baselines. Enforcement, while strong in principle, proves variable in practice. Some contexts apply rigorous inspection and oversight, including seismic retrofit enforcement and independent audits, while others depend on voluntary compliance or fragmented systems with uneven enforcement across states and weak municipal implementation capacity.

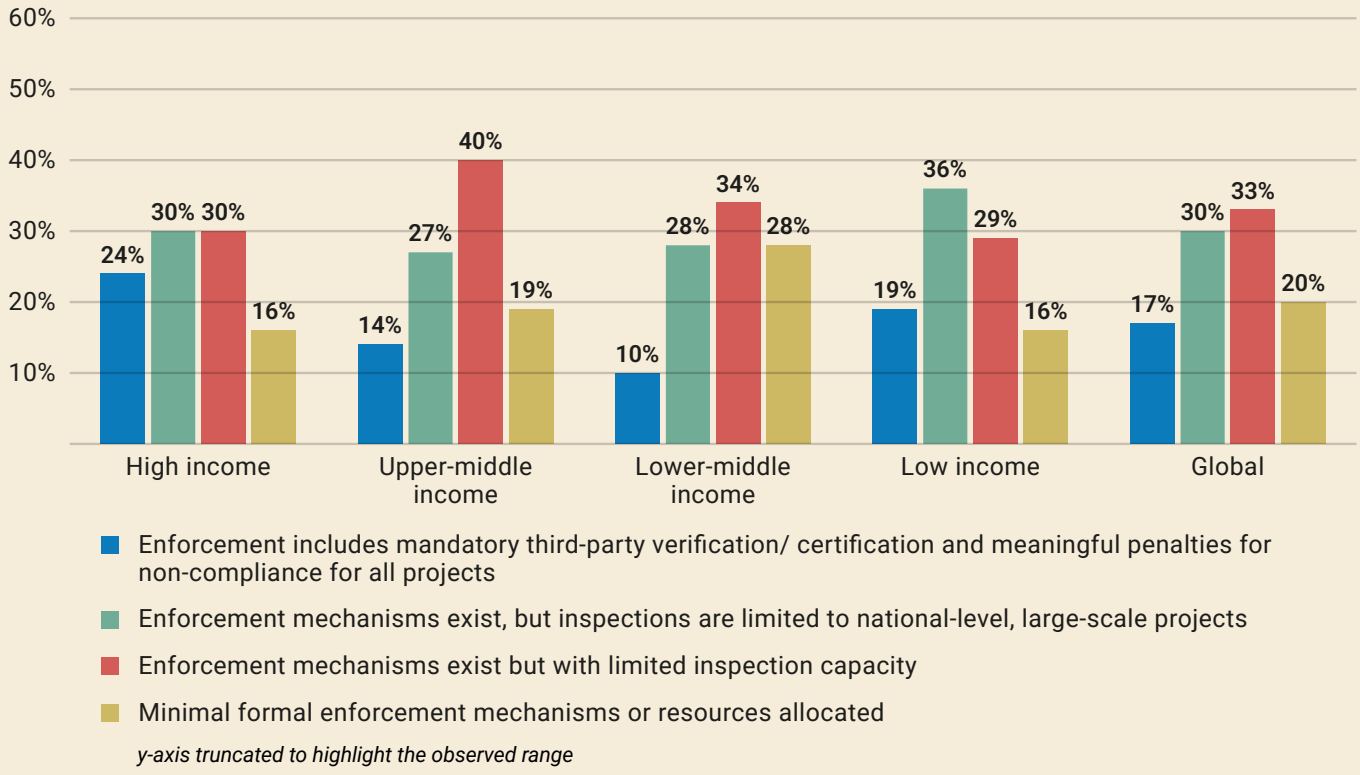


Figure 27

Enforcement of regulations, codes, and standards, by country income level

Source: Authors' analysis

Questionnaire responses from upper-middle-income countries show slightly higher perceived adequacy at 25 percent, though expert interviews suggest significant underlying challenges. Experts explained in interviews and FGDs how codes generally exist across sectors, often developed or updated after major disasters, but are largely based on historical hazard experience and rarely include climate projections. Seismic codes dominate the regulatory landscape, with some jurisdictions requiring risk assessments alongside seismic standards. Enforcement is inconsistent—stronger where national institutions require compliance for public projects but usually weak at the municipal level, leading to widespread non-compliance. The interviewed experts perceived that where national enforcement is strong, municipal enforcement is weak; outdated codes remain unenforced, the shortage of inspectors undermines implementation, and compliance is non-existent beyond donor-supported projects.

Responses from lower-middle-income countries show the lowest perceived adequacy at 16 percent, with more than a quarter (27 percent) of the respondents describing regulations as having limited adequacy. Expert interviews confirm that codes, while present, are outdated, partial, or unevenly enforced. They may be robust in some sectors—for example, strong earthquake codes for seismic safety—but enforcement varies sharply between large cities and rural areas. Codes are poorly applied outside major cities, with standards limited to donor-backed projects. Climate integration remains absent across the board.

Responses from low-income countries record the highest adequacy rating at 31 percent, although a majority (53 percent) of the respondents see frameworks as insufficient. Expert interviews suggest that this apparent adequacy may reflect the adoption of international standards or recent donor-driven improvements rather than fully effective regulations; in reality, although codes exist in law, they are rudimentary and rarely implemented. Climate change is largely absent from standards, with rare exceptions where resilience considerations have been added to updated building codes and transport manuals. Enforcement is the

weakest in all income groups, constrained by shortages of inspectors, technical staff, and funding, leaving most construction projects outside effective oversight.

These findings suggest that while regulatory frameworks may exist on paper, their implementation is uneven, selective, and often resource-constrained.

Regional analysis

Regional analysis reinforces these patterns while revealing distinct geographic variations (**Figures 28 and 29**). Between 50 and 78 percent of the respondents from every region reported that regulations exist but are outdated or incomplete, while perceived adequacy ratings range from just 12 percent in North America to 36 percent in East Asia and the Pacific.

East Asia and the Pacific had the highest share of respondents (36 percent) who reported regulations and codes as adequate. Expert interviews indicate that high-income contexts in the region have some of the strongest codes worldwide, with comprehensive frameworks across sectors. Several jurisdictions integrate climate risks—including coastal flood risk and rainfall standards based on climate projections—though most still rely on traditional hazard data, particularly for seismic codes. However, in lower-income contexts within the region, codes have limited reach, and enforcement is weaker, limited to donor-funded projects or capital cities. There are only partial sectoral codes, and no national framework exists.

The North America region has the lowest proportion of respondents (12 percent) rating regulations as adequate, despite the existence of comprehensive codes covering multiple sectors. Expert interviews shed light on this apparent contradiction: While climate integration is stronger in some jurisdictions, with climate projections embedded in codes, others rely on outdated hydrological baselines. More critically, experts perceived enforcement to be inconsistent, varying by province or state, with strong compliance in hurricane-prone states but weak elsewhere (McAllister et al., 2022).

In Latin America and the Caribbean, 25 percent of the respondents perceived existing regulations, codes, and standards as having limited adequacy. Expert interviews suggest that while the countries in this region maintain seismic and building codes, many of them are outdated or incomplete, and few explicitly integrate climate risk. Codes remain largely based on historical hazard data, with donor-supported updates occasionally adding climate elements. Enforcement emerges as the main weakness: Although national frameworks exist, municipalities lack staff—especially inspectors—and funding, leading to widespread non-compliance and low overall enforcement.

The Sub-Saharan Africa region stands out with questionnaire responses showing a relatively higher share of ratings of perceived adequacy at 27 percent; the majority of respondents in this region, however, regarded standards as insufficient. Expert interviews reveal that countries often adopt international standards, including the International Organization for Standardization, British and French frameworks, but adaptation to local hazards and climate conditions is limited. As one expert noted, “None of our codes or standards include climate change projections.” Enforcement is generally weak, undermined by resource constraints and siloed institutions. Compliance is stronger in capital cities or donor-funded projects but is almost absent elsewhere due to limited inspection capacity and inadequate enforcement mechanisms.

The Europe and Central Asia region has extensive codes supported by regional directives and standards, such as Eurocodes. However, climate integration is uneven: Some jurisdictions

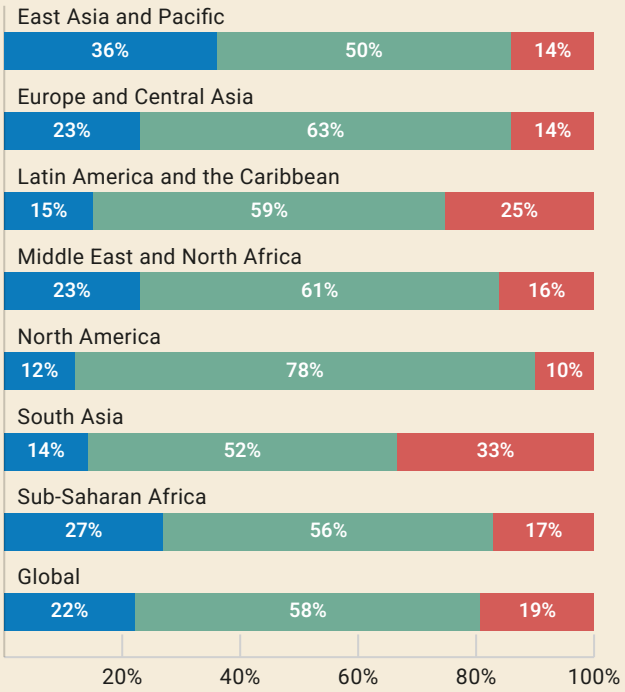


Figure 28

Regulations, codes, and standards, by GIR 2023 region

Source: Authors' analysis

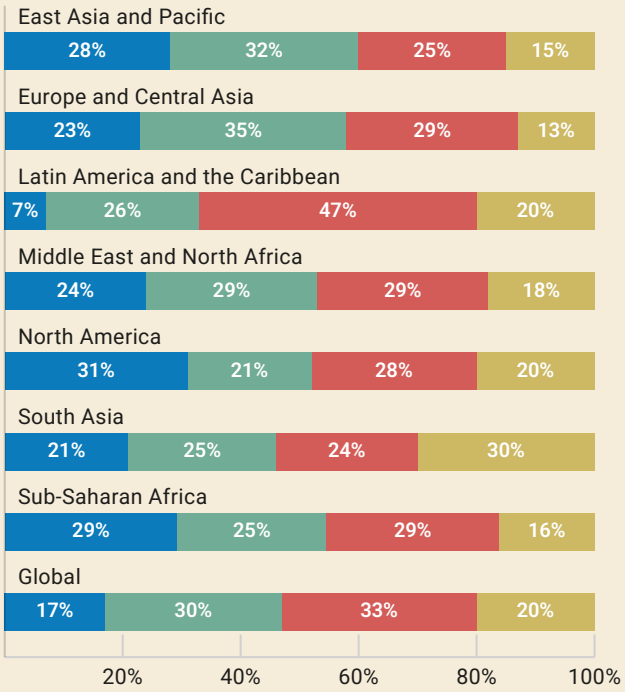


Figure 29

Enforcement of regulations, codes, and standards, by GIR 2023 region

Source: Authors' analysis

systematically embed climate scenarios in standards, but most rely on historical data. Experts revealed in their interviews that enforcement is highly variable, strong in contexts with dedicated institutions, such as specialized water boards, and robust audit systems but fragmented where oversight is relegated to multiple agencies with weak capacity and inconsistent implementation. One expert pointed out that "the problem is not the existence of the code but the follow-up and enforcement."

In the South Asia region, 33 percent of the respondents reported that current regulations, codes, and standards have limited adequacy. Expert interviews confirm significant gaps in both adequacy and enforcement. Respondents from the Middle East and North Africa region reported that codes usually align with international frameworks but climate integration is largely absent, and enforcement varies from high-capacity hubs with mandatory sustainability frameworks to municipalities with inadequate capacity and weak rural implementation.

Enforcement analysis reveals that robust systems with mandatory third-party

verification and meaningful penalties are rare, ranging from just 7 percent in Latin America and the Caribbean to 31 percent in North America. Latin America stands out for enforcement weaknesses, with nearly half the respondents (47 percent) pointing to limited inspection capacity and 20 percent reporting minimal enforcement. South Asia has the highest share of respondents (30 percent) noting minimal enforcement, underscoring systemic resource and institutional challenges.

Discussion

Findings from this study highlight three key weaknesses limiting the effectiveness of regulations, codes, and standards. First, they rely predominantly on historical hazard data, leading to misalignment with evolving risk profiles. Second, enforcement is limited and concentrated on large-scale projects, leaving smaller infrastructure largely unmonitored. Third, gaps persist between national frameworks and local implementation, as municipalities often lack the resources, staff, and technical expertise for effective enforcement.

The counterintuitive finding that respondents from some lower-income countries reported higher adequacy of codes than those from high-income nations likely reflects different baseline expectations rather than the objective superiority of codes. Expert interviews suggest that recent donor-driven improvements in low-income contexts may be the reason for respondents' perception of regulatory advancement, while professionals in high-income countries hold their systems to higher standards and are more aware of gaps in climate integration.

The interviews highlight public procurement processes as a powerful lever for embedding resilience into infrastructure projects, influencing decisions from the earliest stages of design and planning to long-term operations and maintenance. By explicitly including resilience considerations in tendering and contracting, governments and project owners can steer the market towards designs, materials, and construction practices that are better able to withstand climate impacts and natural hazards. This requires setting clear qualification criteria for bidders to demonstrate expertise in resilient design as well as defining measurable resilience indicators and performance metrics that projects must meet. Using performance-based specifications—that is, focusing on outcomes such as flood resistance, adaptive capacity, and durability rather than narrowly defined technical solutions—ensures that resilience is embedded throughout the project's life cycle (OECD, 2021). In addition, integrating whole-life costing into procurement decisions is essential to capture the long-term economic, environmental, and social benefits of resilient infrastructure.

The priority is not simply to establish regulatory frameworks but to ensure that they are regularly updated, aligned with current hazards, and applied across all regions, income levels, and project scales. Adequate resourcing for enforcement is essential to reduce future exposure and avoid costly retrofits or failures. The critical implementation gap lies not in the existence of regulations, which are present in most contexts, but in their relevance, currency, and enforcement. Without updating codes to reflect evolving climate risks, strengthening inspection capacity at all levels, and extending oversight beyond flagship projects to routine construction, regulations will continue to fall short of delivering resilient infrastructure systems.

Box 5

Case study:
Advancing climate-resilient standards in Canada

Canada is investing in climate-resilient codes and standards through two major initiatives (Canada Mortgage and Housing Corporation, 2025). The Climate Resilient Built Environment (CRBE) initiative (2021–2028), led by the National Research Council with Canadian $ (CAD) 35 million in funding, develops science-based knowledge, tools, and technical solutions to guide updates to building and infrastructure codes. Its research spans NbS for flooding, erosion, and heat; resilience of major public assets; tailored guidance for northern and remote communities; and improved asset management. Building on the earlier Climate-Resilient Buildings and Core Public Infrastructure programme, CRBE ensures that resilience is embedded across the full infrastructure life cycle.

In parallel, the Standards to Support Resilience in Infrastructure Program (2021–2026), led by the Standards Council of Canada with CAD 11.7 million in funding, is advancing 36 new standards and technical guidance. These include updates to the National Building, Fire, Plumbing, and Energy Codes as well as sector-specific revisions. The Canadian Highway Bridge Design Code (CSA S6) is being revised for its 2025 edition to incorporate projected climate conditions and extreme events (Kennedy et al., 2022), while the Canadian Electrical Code (CSA C22) has added provisions such as enhanced flood protection. Complementing these instruments, the Public Infrastructure Engineering Vulnerability Committee (2024) Protocol, developed by Engineers Canada and partners, provides a nationally recognized methodology for assessing climate risks to infrastructure.

4. Finance

The finance theme assessed the adequacy and prioritization of funding for resilient infrastructure and the mechanisms through which financial resources are mobilized. Questions explored whether government funding is sufficient to meet current disaster risks and future climate impacts, where resources are directed within infrastructure systems, and the effectiveness of PPPs in addressing resilience needs. The study also examined the extent to which financial instruments, such as bonds and insurance, are being utilized to support resilience, providing a clearer picture of both strengths and gaps in current financing arrangements.

4.1 Adequacy of Government Funding

Sustainable infrastructure resilience demands long-term, predictable public investment, not just as a response measure but also in proactive planning, maintenance, and adaptive upgrades. Investing in resilience is not only cost-effective but also a strategic necessity to foster public safety, economic productivity, and development. Resilience funding should span the entire infrastructure life cycle, beginning with the design and implementation of new infrastructure that is risk-informed and climate-adaptive. Allocating resources to ensure that new assets meet the updated codes and standards helps reduce the risk of future exposure, prevent failures, and avoid costly retrofits.

Equally critical is funding for retrofitting existing infrastructure. Many assets, especially in low- and middle-income countries, were built without accounting for climate and disaster risks. Retrofitting programmes require significant capital investment to enhance the performance of vulnerable assets, yet these programmes yield high returns by reducing losses and service disruptions. Ongoing risk-based maintenance and repair is another, often overlooked, funding need. Infrastructure deteriorates over time, and without regular upkeep aligned with evolving hazard profiles, even resilient designs can become vulnerable. Post-disaster funding is also vital for timely repair and reconstruction, as it enables communities to restore essential services and ‘build back better’ by embedding resilience into recovery efforts.

KEY FINDING 6

Nearly half the questionnaire respondents reported that government funding meets less than a quarter of infrastructure resilience needs, and that maintenance and retrofitting were consistently underfunded compared with post-disaster spending. This creates a cycle in which avoidable damage accumulates while most resources go to recovery. The interviewed experts pointed out that political causes, such as missing dedicated resilience budgets, the low visibility of maintenance, and a preference for new construction, are as important as overall fiscal capacity.

Global trends

Online questionnaire results and expert interviews converge on the conclusion that government funding for infrastructure resilience is widely perceived as 'inadequate'. Interview experts noted that although budgetary frameworks often exist, allocations are largely reactive rather than proactive, maintenance is persistently underfunded, and few governments maintain dedicated resilience budget lines.

Funding gaps vary by activity (**Figure 30**). For new infrastructure, 49 percent of the respondents reported coverage below 25 percent, and only 16 percent believed that it met more than 75 percent of needs. This pattern is consistent across the building sector and other infrastructure sectors and across government and private-sector perspectives. Retrofitting faces the most severe constraints, with 60 percent of the respondents reporting that funding met less than 25 percent of needs, and only 9 percent seeing it as adequate.

Risk-based maintenance and repair is similarly underfunded, with 60 percent of the respondents reporting coverage below 25 percent. Post-disaster repair and reconstruction received relatively better, though still limited, support: 45 percent of the respondents reported coverage below 25 percent, and 19 percent estimated above 75 percent coverage. This suggests that governments should prioritize visible post-disaster response over preventive measures.

Globally, chronic under-investment is evident, especially for retrofitting and maintenance (only 9 percent of the respondents noted that funding covers at least 75 percent of needs). These patterns reveal a systematic bias in resilience funding, with reactive reconstruction receiving more resources than proactive measures despite the latter being more cost-effective. Experts emphasized that even where investment amounts appear substantial, allocations rarely match the assessed resilience needs and long-term priorities are often sidelined in favour of short-term or politically visible projects. This persistent underfunding, particularly for preventive measures, leaves infrastructure vulnerable to escalating climate and disaster risks.

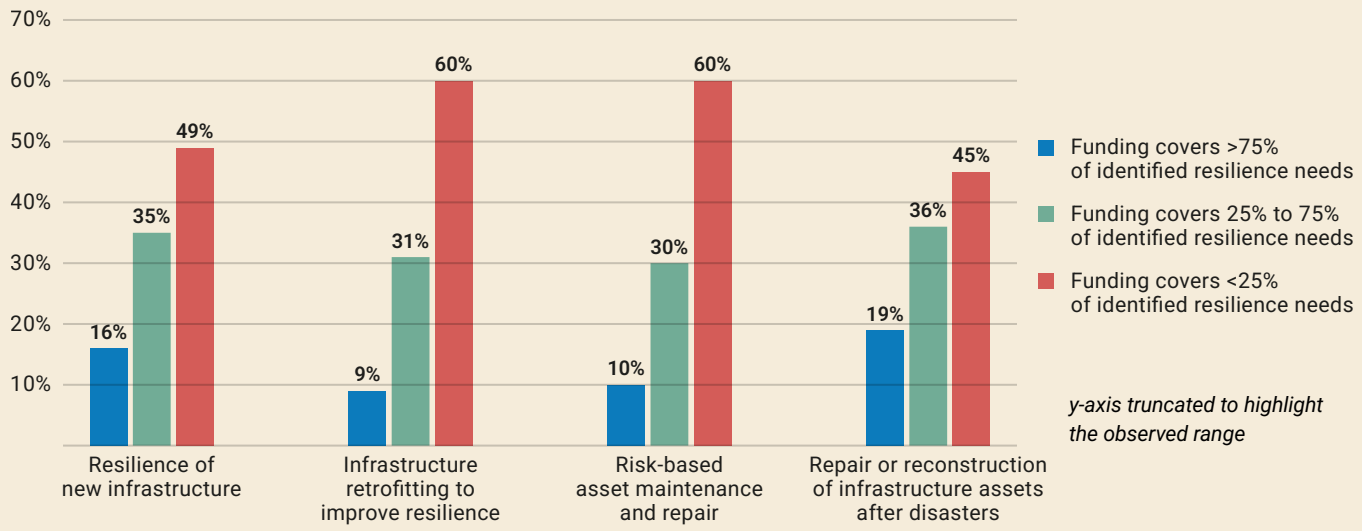


Figure 30

Adequacy of government funding for implementing resilience in new infrastructure, retrofitting infrastructure, risk-based asset maintenance and repair, and post-disaster infrastructure repair and reconstruction—a global overview

Source: Authors' analysis

Country income level analysis

Across all country income levels (**Figures 31–34**), respondents reported that adequate funding for infrastructure resilience is the exception rather than the rule, with support generally declining as income levels fall, except for an unexpected reversal in low-income countries.

Lower-middle-income countries face the most acute funding crisis. For new infrastructure, 59 percent of the respondents from these countries reported funding coverage below 25 percent of needs. This rose to 70 percent for retrofitting and maintenance—the highest share of inadequacy responses across all groups. The interviewed experts confirmed this perception, citing debt service obligations, operations and maintenance backlogs, and donor dependence as severe constraints. When disasters occur, reconstruction costs routinely exceed fiscal capacity, leaving countries reliant on external loans, which further compound debt burdens.

Substantial gaps emerge from the responses from high-income countries, with over half indicating funding below 25 percent of needs for retrofitting (54 percent) and maintenance (53 percent). The interviewed experts noted that inadequacy persists due to underfunding of local governments, reliance on post-disaster allocations rather than proactive investment, and sectoral imbalances. Shortfalls relative to resilience needs, insufficient budget allocation, and backlogs in energy infrastructure, despite stable water-sector funding, are frequently observed.

Respondents from upper-middle-income countries noted similar inadequacy, with around half reporting funding below 25 percent across most categories. Expert interviews highlight chronically low maintenance budgets, dependence on donors, and prioritization of new construction. Disasters sometimes trigger temporary funding injections, but political turnover, weak budget execution, and continued donor dependence undermine policy continuity.

Low-income countries had the highest perceived adequacy responses, with 21 percent indicating funding above 75 percent of needs for new infrastructure and post-disaster reconstruction. The interviewed experts explained that this reflects heavy reliance on donor and international support rather than robust domestic budgets. Nevertheless, resilience elements are rarely budgeted

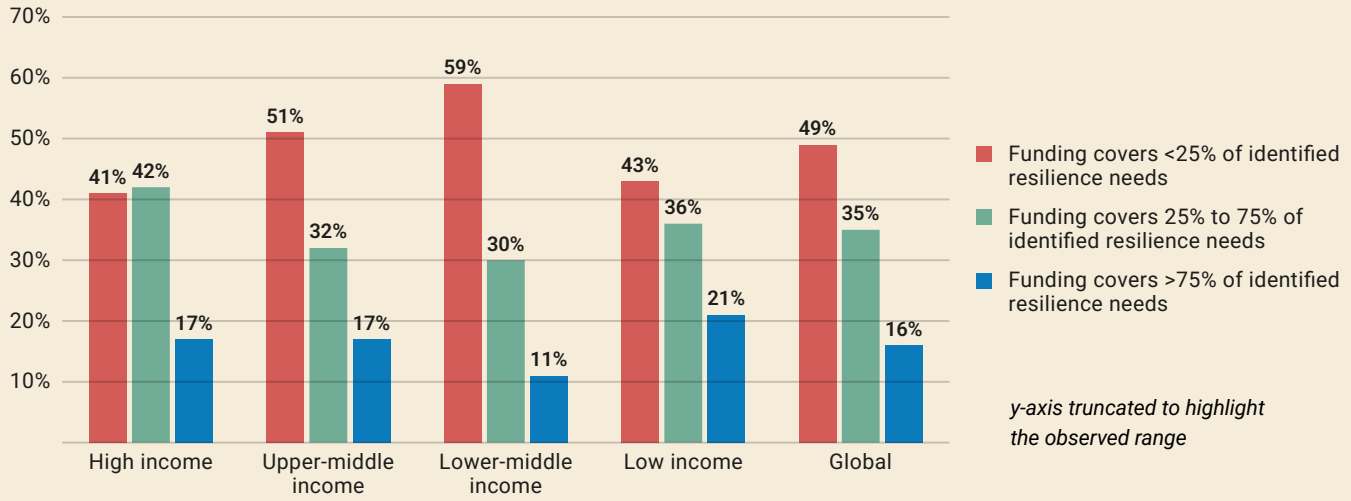


Figure 31

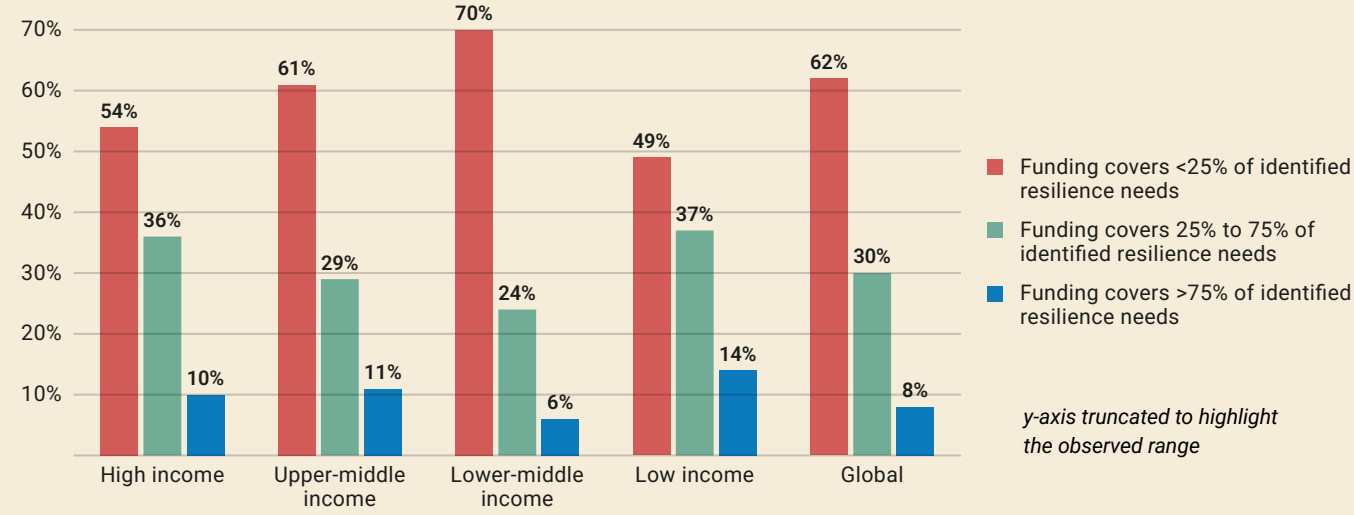
Adequacy of government funding for the implementation of resilience of new infrastructure, by income group

Source: Authors' analysis

Figure 32

Adequacy of government funding for retrofitting infrastructure, by income group

Source: Authors' analysis



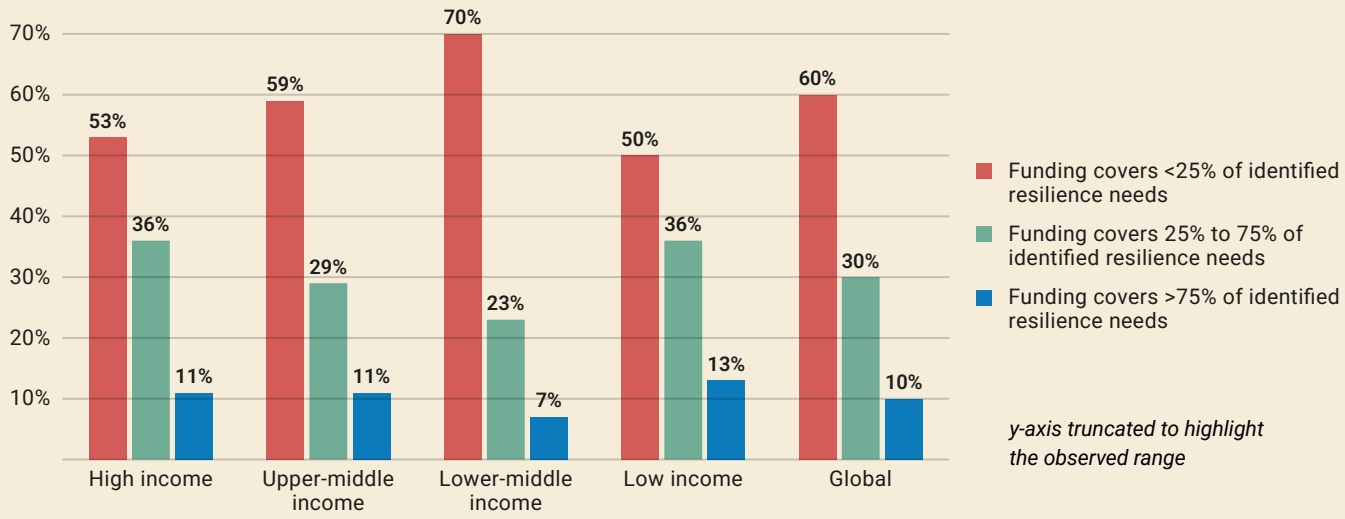


Figure 33

Adequacy of government funding for risk-based asset maintenance and repair, by income group

Source: Authors' analysis

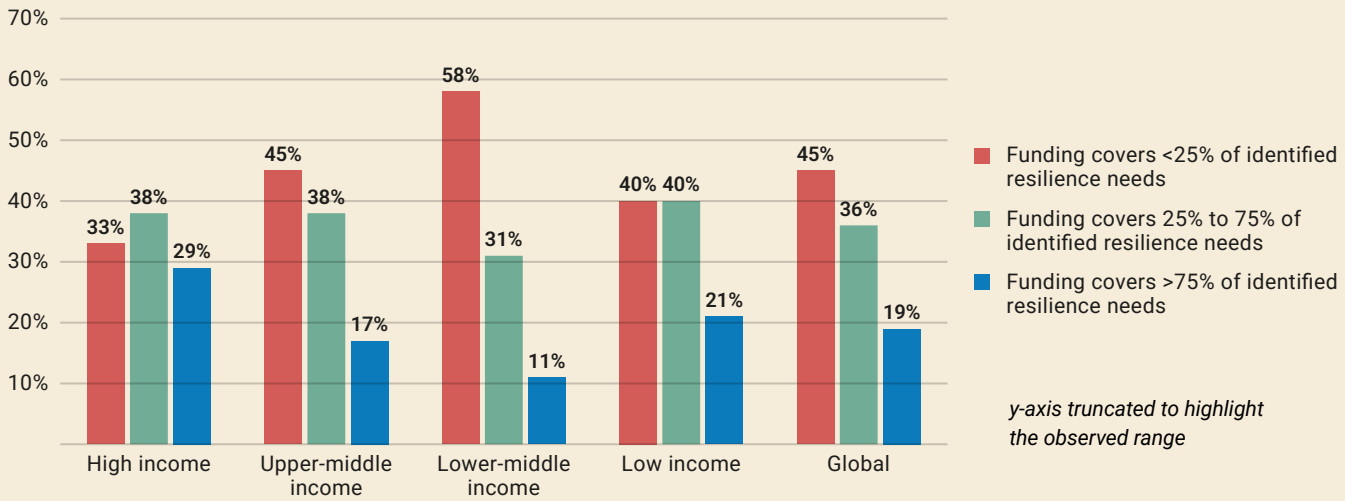
proactively, new construction is prioritized, and disaster losses regularly exceed the available resources.

A consistent pattern emerges across all income levels: Post-disaster reconstruction receives higher funding than proactive measures. Respondents from high-income countries reported 29 percent adequacy for reconstruction versus 10–11 percent for retrofitting and maintenance. This reactive bias is even more pronounced in upper-middle-income countries and persists across all groups, indicating a systemic preference for visible disaster response over preventive investment.

Figure 34

Adequacy of government funding for post-disaster infrastructure repair and reconstruction, by income group

Source: Authors' analysis



Regional analysis

Questionnaire respondents revealed stark disparities in funding adequacy that often go beyond country income levels (**Figures 35–38**), indicating that institutional factors and political priorities strongly influence investment in resilience.

Respondents from Latin America and the Caribbean reported the most severe funding gaps, with 73 percent citing retrofitting funding and 74 percent maintenance funding below 25 percent of needs. Expert interviews highlight systemic challenges, including under-investment in maintenance, heavy donor dependence, and politically driven allocations prioritizing visible new projects. Recovery remains reactive, resilience budgeting is rare, and budget execution is frequently blocked or diverted, with dependence on external funds for critical upgrades.

In East Asia and the Pacific, as well as the Middle East and North Africa, around a quarter of the respondents reported adequate funding for maintenance and reconstruction. Interviewed expert insights, however, reveal persistent weaknesses: Funding is often variable, local governments are underfunded, resilience considerations are absent in utility regulation, and long-term risks are under-financed. Even substantial resources are insufficient to meet needs across sectors and governance levels.

Respondents in Europe and Central Asia presented a mixed picture: Their countries benefit from regional and national funds but face implementation gaps. The interviewed experts noted bureaucratic bottlenecks, lack of earmarked resilience funds, and sectoral imbalances. Flood protection is supported by dedicated water boards, yet the energy and transport sectors experience persistent backlogs, and recovery fund disbursements are often delayed.

In North America, nearly half the respondents reported funding below 25 percent of needs for new infrastructure. The interviewed experts emphasized that, despite the large federal programmes, allocations cover only a fraction of annual requirements, with cuts to key mitigation programmes limiting overall adequacy.

Respondents in Sub-Saharan Africa reported severe underfunding across categories. Expert interviews highlighted competing fiscal priorities, limited climate finance access, and persistent maintenance backlogs. Similarly, over half of the South Asian respondents noted funding below 25 percent for post-disaster reconstruction, and 74 percent perceived severe underfunding for maintenance. In the Middle East and North Africa, wealthier hubs can mobilize sovereign and green finance, but resilience funding remains fragmented and reactive in other contexts.

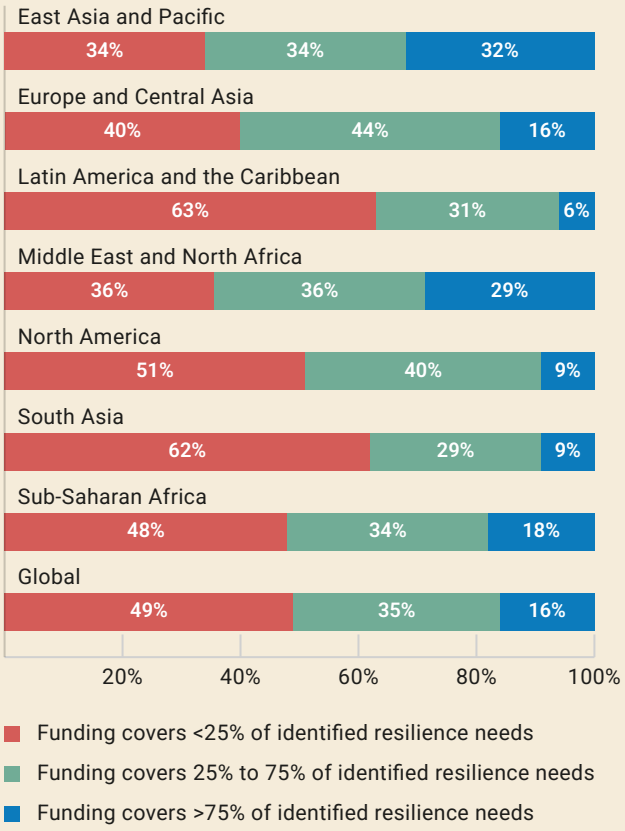


Figure 35

Adequacy of government funding for the implementation of resilience of new infrastructure, by GIR 2023 region

Source: Authors' analysis

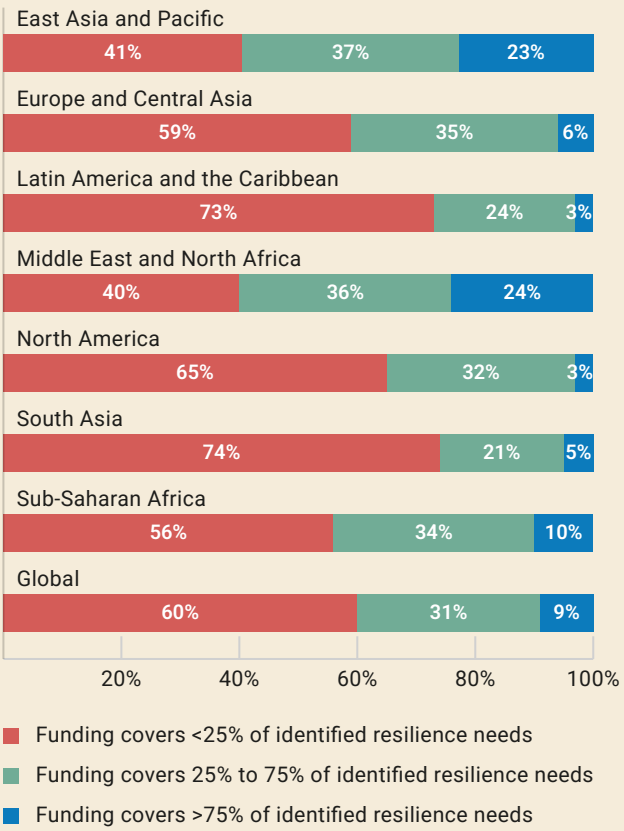


Figure 36

Adequacy of government funding for retrofitting infrastructure, by GIR 2023 region

Source: Authors' analysis

Discussion

These findings reveal a global resilience financing shortfall that cuts across simple income categorizations. The systematic underfunding of proactive measures—particularly towards maintenance and retrofitting—in favour of reactive post-disaster spending creates a vicious cycle in which preventable losses continue to mount, absorbing resources that could have been invested in risk reduction.

Survey results from high-income countries indicate similar or even lower funding adequacy compared with lower-income contexts, highlighting that political and institutional factors can be as important as fiscal capacity. Expert interviews consistently point to the absence of dedicated resilience budget lines, the political invisibility of maintenance, and a tendency to prioritize new construction over upgrading existing assets.

The role of international support emerges as both crucial and problematic. While it explains the relatively better performance of some low-income countries, this dependence creates vulnerability to donor priorities and funding cycles, undermining the assured, long-term investment that resilience requires.

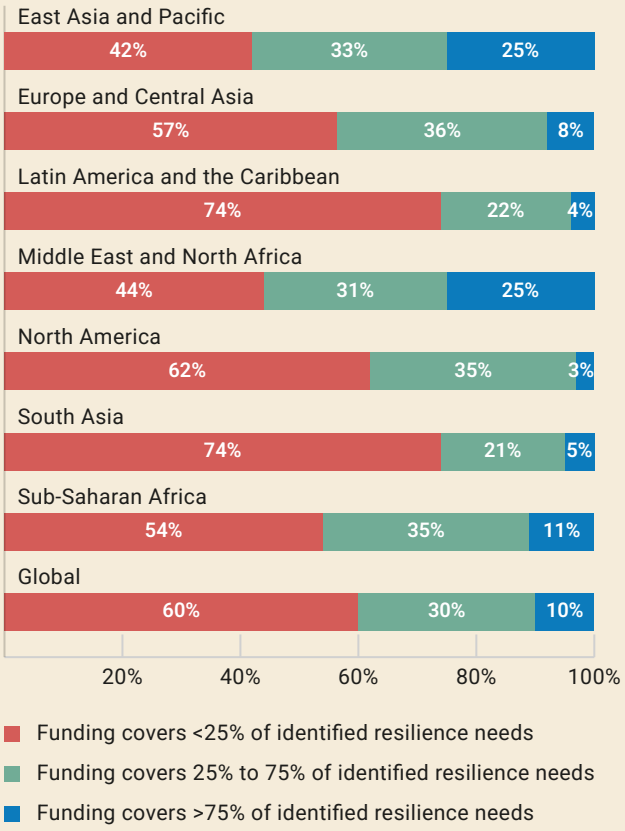


Figure 37

Adequacy of government funding for risk-based asset maintenance, by GIR 2023 region

Source: Authors' analysis

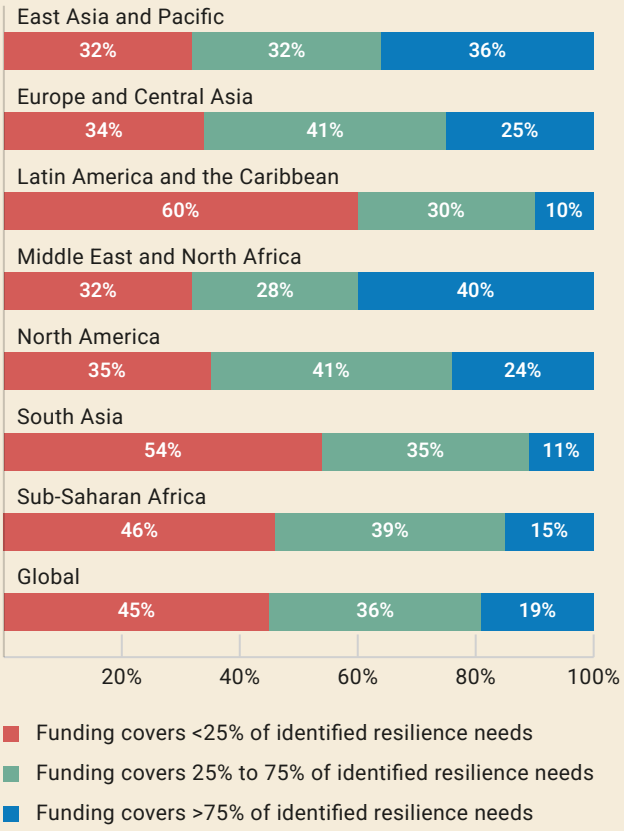


Figure 38

Adequacy of government funding for post-disaster infrastructure repair and reconstruction, by GIR 2023 region

Source: Authors' analysis

Fundamental shifts are needed in how resilience is valued, budgeted, and prioritized within national fiscal frameworks; otherwise, infrastructure systems will continue to face escalating climate and disaster risks with inadequate resources for either prevention or recovery. The evidence points to the need not just for more funding but also for systemic reforms that embed resilience considerations throughout budget cycles and create protected funding streams for less visible but critical investments in maintenance, retrofitting, and proactive risk reduction.

4.2 Financial Mechanisms for Infrastructure Resilience

Financial mechanisms such as PPP contracts, thematic bonds, and insurance are critical enablers of disaster-resilient infrastructure. PPP contracts can mobilize private-sector expertise and capital for resilience by embedding risk assessment, climate adaptation standards, and life-cycle maintenance obligations directly into contractual terms. This ensures that resilience is not an optional add-on but a core delivery requirement throughout the project's life.

Further, climate risk and catastrophe insurance can provide quick liquidity after a disaster, enabling timely repair and reconstruction while protecting public budgets. Parametric insurance, in particular, can speed payouts by linking triggers to measurable hazard parameters.

Thematic bonds, including green, resilience, or sustainability bonds, offer governments and infrastructure owners a targeted way to raise capital for resilience-focused projects, such as flood defences, retrofitting programmes, and NbS. These instruments attract socially responsible investors by linking returns to measurable environmental and social benefits, while improving transparency in the use of funds.

KEY FINDING 7

Innovative finance mechanisms for resilience remain confined to pilot or flagship projects and are not systematically applied to all programmes. While PPPs are somewhat more visible, with only 15 percent reporting consistent integration across regions, thematic bonds and insurance tools show only early-stage uptake. In low- and middle-income countries, these tools are used mostly in donor-backed pilots. This indicates that the potential of blended and innovative finance for resilience is far from realized, underscoring the need for stronger enabling frameworks, demonstration projects, and policy incentives to scale these mechanisms beyond niche applications.

Global trends

Across financing instruments, perceptions reveal a clear pattern of limited and selective use, with none of these tools yet fully mainstreamed into resilience strategies. PPPs emerge as the most established mechanism, with half the respondents noting selective use in high-profile projects, although only 15 percent of questionnaire responses indicate consistent integration. Thematic bonds remain nascent, with 62 percent of responses reporting no or rare use and just 7 percent indicating consistent application. Insurance mechanisms occupy a middle ground, with 11 percent of responses noting consistent integration—slightly higher than for bonds but still a modest number. These findings suggest that innovative finance for resilience remains concentrated in pilot or flagship projects and is not used systematically.

Stakeholder perspectives show modest variations that reflect their different roles within the financial ecosystem. Responses from government and the private sector had identical patterns for PPPs, with around half the respondents noting selective application and only a seventh reporting consistent use. Private-sector respondents displayed slightly higher optimism across all mechanisms, probably due to their direct involvement in flagship projects where innovative finance is more commonly deployed.

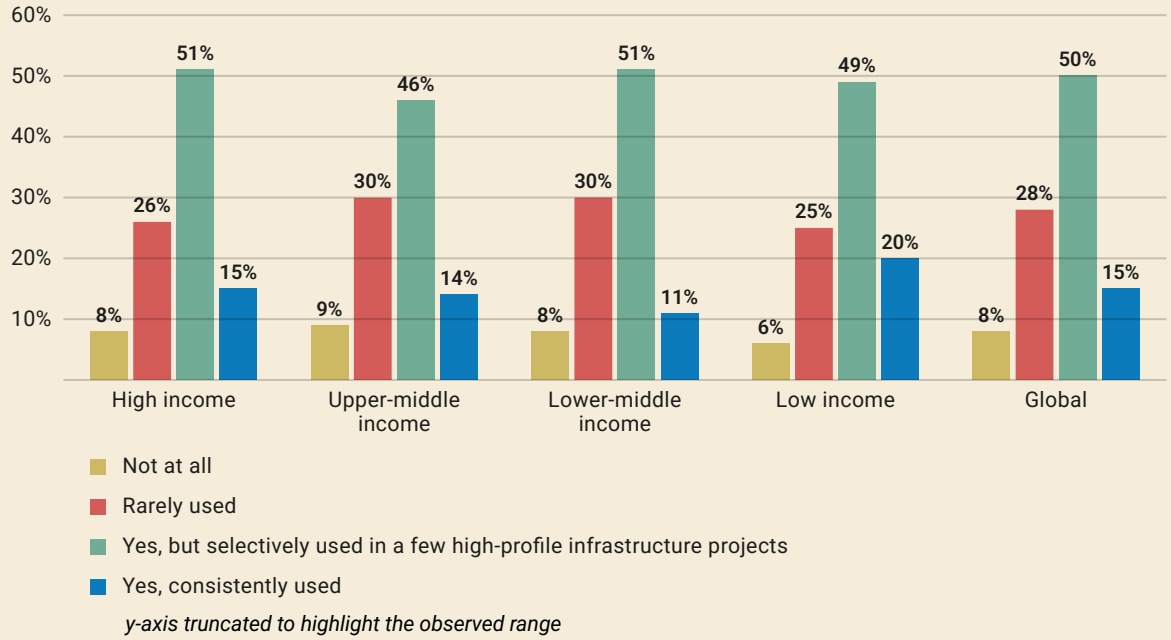


Figure 39

Use of PPP contracts to enhance infrastructure resilience, by income group

Source: Authors' analysis

Sectoral differences are minimal, with the buildings sector and other infrastructure sectors eliciting nearly identical patterns of responses across all mechanisms. This similarity of perspectives suggests that barriers to innovative finance are systemic rather than sector-specific and cut across different types of projects and investments.

Country income level analysis

The deployment of financial mechanisms reveals unexpected patterns across country income levels, with questionnaire responses from low-income countries sometimes indicating higher uptake than those from wealthier nations. This suggests that donor influence and the necessity to address urgent risks may drive innovation more than fiscal capacity alone.

In the case of PPPs (**Figure 39**), results for high-income countries show the highest level of perceived selective use at 51 percent of the responses, while low-income countries have the highest number of responses noting consistent use at 20 percent. However, while questionnaire responses provide evidence of consistent or selective PPP use, experts cautioned that across most income groups—except for high-income countries—resilience considerations remain largely incidental (World Bank, 2019). Expert interviews indicate that in low-income countries, PPPs in the housing, water, and transport sectors are supported by climate funds, though resilience clauses are generally absent in the contracts.

Insurance mechanisms show a similar pattern (**Figure 40**), with low-income countries having the highest number of respondents (16 percent) reporting consistent use. Expert interviews suggest that this figure reflects targeted, donor-supported risk transfer schemes rather than well-developed domestic insurance markets. In contrast, experts highlighted more sophisticated applications in high-income countries, such as premium discounts for flood-proofing and resilient construction, catastrophe bonds for disaster risk transfer, and insurance integrated into blended finance packages. Results from middle-income countries show emerging innovations, including regional catastrophe insurance pools, but overall market penetration remains limited.

Thematic bonds show even more limited uptake (**Figure 41**), with perceptions of consistent use never exceeding 10 percent of the questionnaire responses

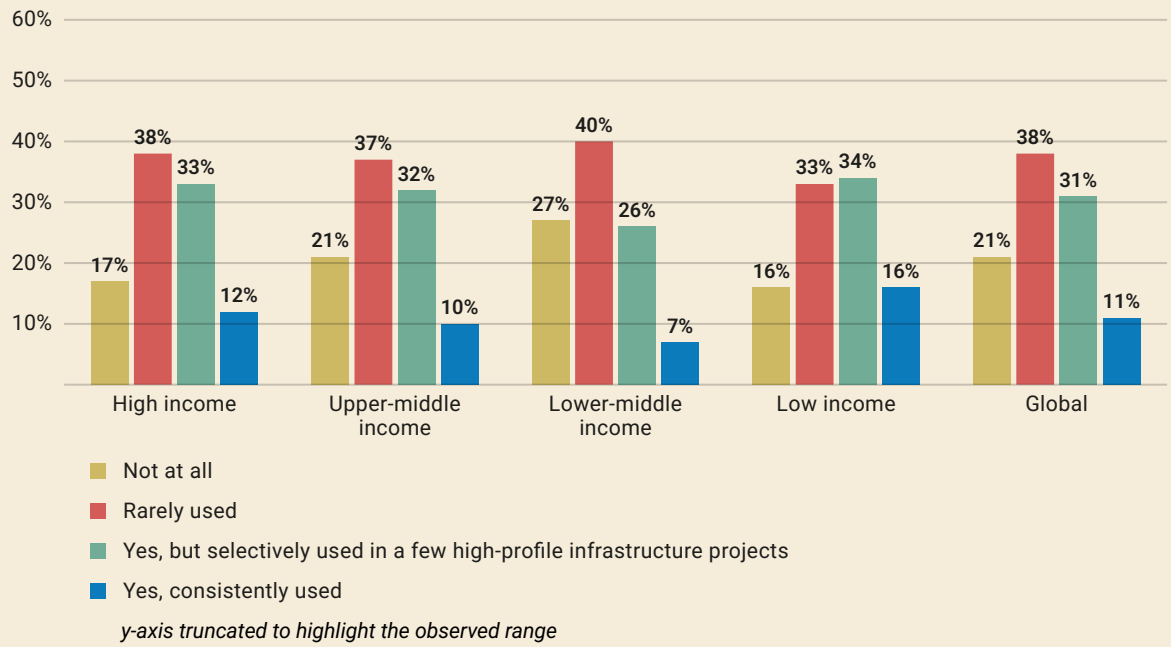


Figure 40

Use of insurance to enhance infrastructure resilience, by income group

Source: Authors' analysis

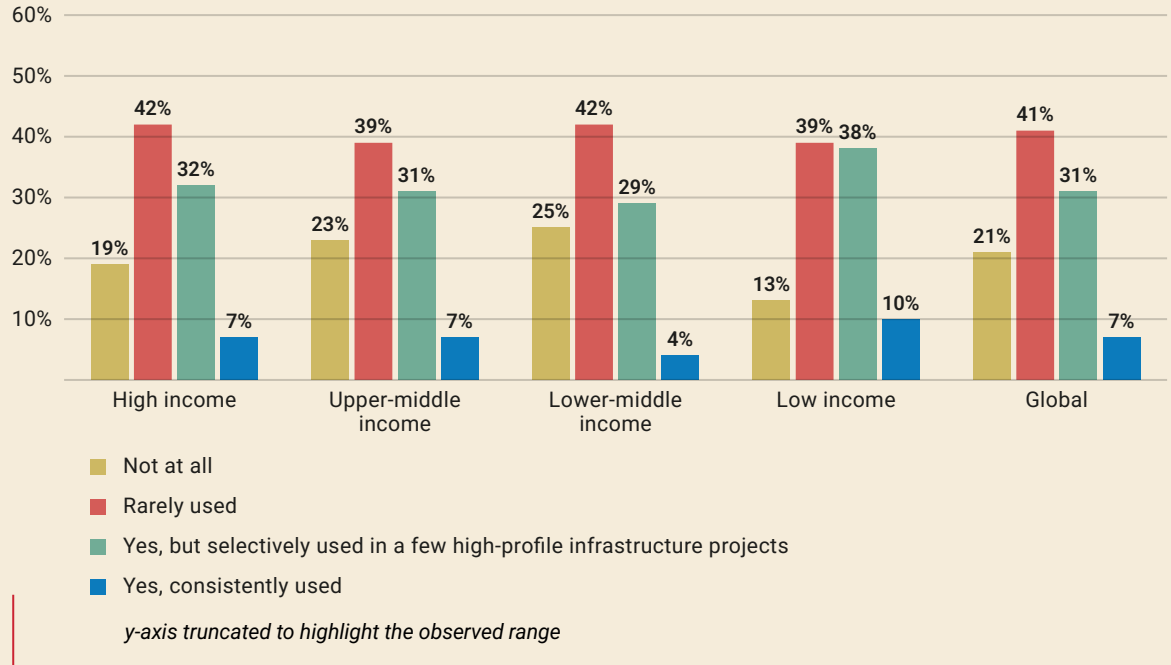
in any income group. The interviewed experts from high-income countries noted that green and sustainability bonds tend to prioritize emissions reduction rather than resilience and adaptation.

Responses from lower-middle-income countries show the weakest uptake, with one quarter of the respondents indicating that such bonds are not used at all.

Figure 41

Use of thematic bonds to enhance infrastructure resilience, by income group

Source: Authors' analysis



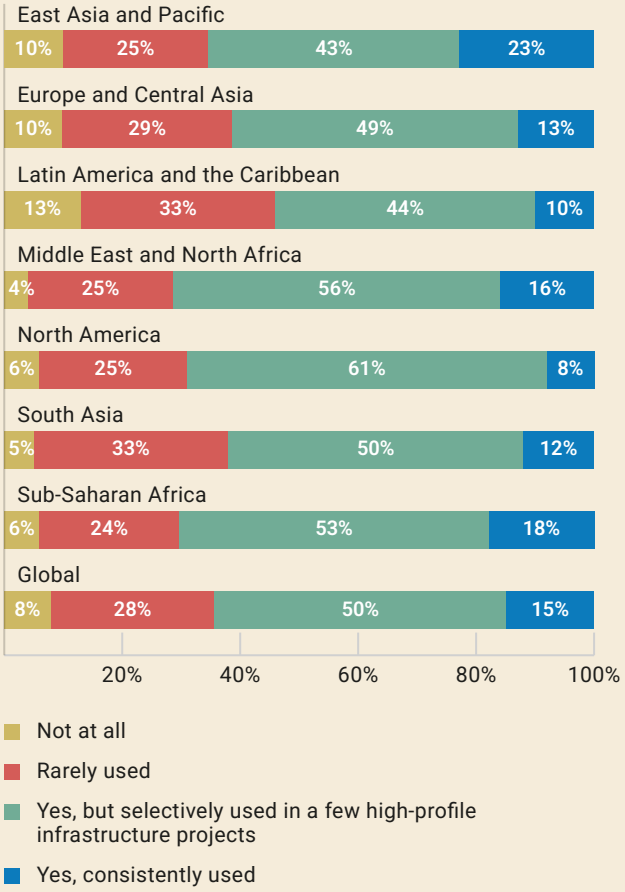


Figure 42

Use of PPP contracts to enhance infrastructure resilience, by GIR 2023 region

Source: Authors' analysis

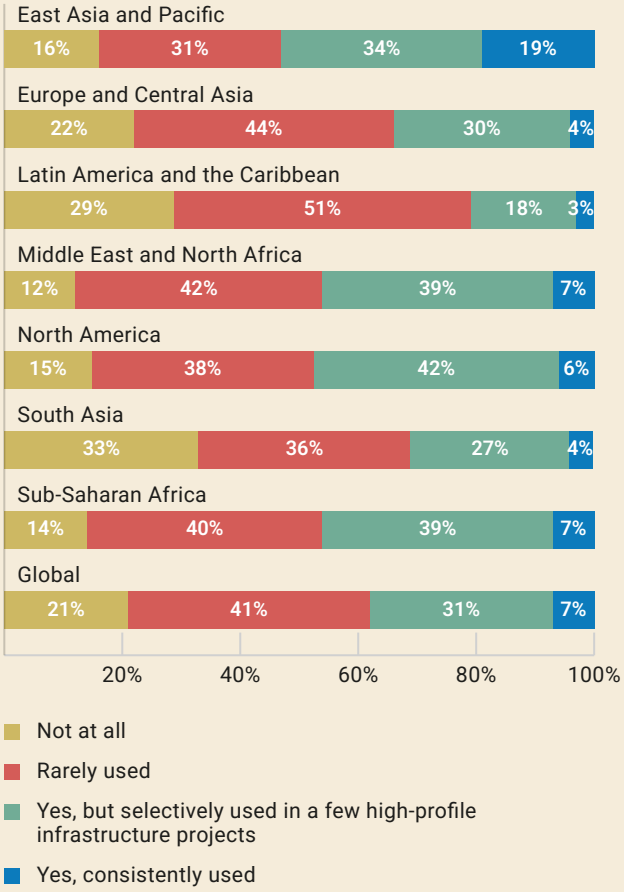


Figure 43

Use of thematic bonds to enhance infrastructure resilience, by GIR 2023 region

Source: Authors' analysis

Regional analysis

Regional patterns reveal how institutional traditions, market maturity, and disaster exposure shape the uptake of financial mechanisms, with significant variation that often transcends country income levels (**Figures 42-44**).

The East Asia and Pacific region emerges as the leader across all three mechanisms, with 23 percent of the respondents reporting consistent PPP use and 19 percent noting the same for thematic bonds. Expert interviews provide additional context: High-income countries in the region demonstrate sophisticated blended resilience finance, including PPP contracts with embedded resilience requirements, catastrophe bonds for risk transfer, thematic bonds linked to infrastructure maintenance, and insurance de-risking mechanisms integrated with project finance. However, lower-middle-income countries primarily use PPPs for energy projects, with limited focus on resilience; thematic bonds are rarely used outside high-income contexts.

Results for Latin America and the Caribbean show the weakest adoption across all mechanisms, with 29 percent of the respondents stating that thematic bonds are not used at all and only 10 percent reporting consistent PPP use. Expert interviews confirm that while PPPs are widespread, they rarely

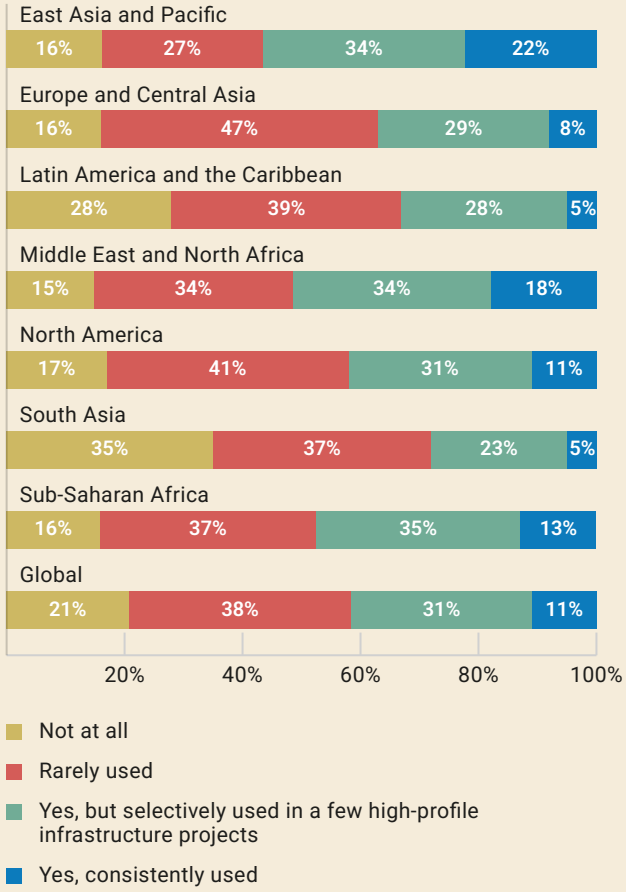


Figure 44

Use of insurance to enhance infrastructure resilience, by GIR 2023 region

Source: Authors' analysis

include explicit resilience requirements. Financing is still largely driven by donor instruments, with international financial institutions and development banks supporting resilience projects, but domestic mechanisms remain underdeveloped. Insurance mechanisms exist through regional schemes and emerging initiatives to ensure infrastructure assets, but overall uptake remains low.

Experts from Europe and Central Asia pointed out that despite the presence of sophisticated financial markets, there is uneven application of resilience measures. While PPPs are common, expert interviews reveal inconsistent integration. Some jurisdictions mandate resilience clauses in concessions, while others use PPPs for seismic retrofits. Yet many of the interviewed experts reported frameworks that neither systematically embed resilience nor extend it to new projects. Thematic and green bonds are increasingly used and are often linked to adaptation or broader sustainability goals. Insurance coverage is expanding, with some sectors requiring compulsory resilience-related policies.

In the Sub-Saharan Africa region, a pattern of fragmentation emerges. Survey responses indicate that PPPs are either consistently or selectively used to finance infrastructure projects, particularly in renewable energy, transport, and housing. However, expert interviews suggest that green bonds are mostly donor-backed sustainability loans supported by development finance institutions. Similarly, insurance use is very limited, except in cases where donor-supported regional pools are in place.

Evidence from the North America region points to surprisingly limited integration of resilience despite the presence of mature markets. Experts note that while PPPs are well established, resilience elements are often minimal: Some contracts include resilience clauses, but most PPP frameworks do not make resilience a central requirement. Insurance plays a relatively larger role through coverage discounts and incentives for resilient construction, while thematic bonds remain underutilized for resilience financing despite the existence of active capital markets.

Results for the Middle East and North Africa indicate active financial mechanisms in high-income hubs but inconsistent linkage to resilience. PPP expansion includes offshore renewable energy projects, and green and sustainability bonds are gaining traction. Insurance and other risk transfer mechanisms are present but are often tied to energy or general sustainability objectives rather than explicitly focused on resilience.

Discussion

Findings show that innovative finance for resilience faces three key barriers that cut across country income levels and regions. First, while instruments such as PPPs, bonds, and insurance are widely available, they rarely include explicit resilience requirements. Second, climate finance remains dominated by mitigation measures (OECD, 2025), with green bonds and sustainability instruments focused on emission reduction rather than resilience. Third, mechanisms are often concentrated in flagship projects rather than integrated across broader infrastructure portfolios.

The stronger uptake in some low-income countries indicates both potential and risk. Donor support can catalyse innovation and provide for risk transfer, but reliance on external initiatives creates vulnerability to changing priorities and funding cycles, and the absence of domestic markets undermines long-term sustainability.

The maturity of mechanisms varies: PPPs are used the most but need stronger resilience mandates; insurance offers promise through premium incentives and parametric triggers but requires market development; bonds need supply- and demand-side growth. Embedding resilience requirements, scaling beyond pilots, and developing domestic markets are essential to realize the full potential of these instruments (UNDRR, 2025).

5. Risk Assessment

Risk assessments are a critical step in the design of new infrastructure assets and systems, as well as in retrofitting existing ones. The quality of these assessments depends largely on the availability of hazard, exposure, and vulnerability data, including future climate projections.

The survey examined the extent to which hazard, vulnerability, and risk data are collected, whether risk assessments are systematically applied in infrastructure design, and the degree to which future risks, including climate scenarios, are incorporated. The research aimed to assess both the availability and the quality of risk information and the extent to which it is effectively embedded in decision-making.

5.1 Use of Climate and Disaster Risk Assessments in Infrastructure Development

Hazard and risk assessments provide the evidence base for designing, upgrading, and maintaining assets to enable them to withstand current and future threats. They identify hazard exposure, asset vulnerabilities, and potential impacts on services and help decision-makers to prioritize investments and select effective mitigation measures.

Mandating hazard and risk assessments in regulations, building codes, and technical standards ensures that resilience is systematically embedded throughout the infrastructure life cycle. Such requirements create a consistent approach, obliging public and private actors to consider site-specific hazard profiles, climate projections, and interdependencies with other infrastructure systems. Integrating risk assessments with formal regulatory frameworks also encourages the use of standardized methodologies, improving comparability, transparency, and accountability. This enhances technical quality and facilitates financing, as investors and insurers can better understand and price risks.

Climate change is altering the frequency, intensity, and distribution of hazards such as floods, storms, heatwaves, and droughts. Hence, historical data alone can no longer be a reliable guide for design and planning. Without taking into account projected climate

KEY FINDING 8

Despite widespread mandates, hazard and risk assessments are applied inconsistently, with only 26 percent of the respondents reporting regular use and just 15 percent noting their use when climate scenarios are included. Infrastructure continues to be designed based on historical data, locking in systemic vulnerabilities. Regional and income-level differences show that while disaster experience drives uptake, forward-looking climate integration remains largely aspirational.

conditions, the infrastructure built today may face premature failure, higher maintenance costs, and increased losses due to disasters. Mandating the inclusion of future climate scenarios in codes, regulations, and technical standards ensures that resilience measures are proactive rather than merely reactive.

Global trends

Across all regions and country income levels, experts emphasized that while hazard and risk assessments are gaining traction, the integration of forward-looking climate risk scenarios remains sporadic, externally driven, and insufficient to address the escalating climate and disaster risks.

Survey findings reveal a critical implementation gap: Although hazard and risk assessments are increasingly mandated, only 26 percent of the respondents reported consistent application, while 43 percent indicated that these mandatory assessments are only sometimes applied. The situation is even more concerning for climate scenarios, with just 15 percent of the respondents noting consistent mandated use despite the growing climate risks. As one expert noted, “Most of our codes and design standards are based on historical data. By definition, that means you’re basing it on how things were in the past—but the future may be very different.”

Stakeholder perspectives highlight notable differences between perception and practice. Private-sector respondents presented the most favourable outlook, with a higher proportion reporting consistent mandated use of risk assessments compared with their government counterparts. Respondents from the non-profit sector reported even lower levels of consistency. This likely reflects the private sector’s involvement in high-profile projects, where assessments are enforced more rigorously or there is greater awareness of implementation gaps due to direct project experience.

Across infrastructure sectors, there is broad acknowledgement that mandated assessments are often applied inconsistently. Compared with the building sector, other sectors show a slightly greater reliance on voluntary or ad hoc practices, suggesting that linear infrastructure projects may more often proceed through alternative assessment pathways.

Integration of climate scenarios displays even weaker consistency. Government respondents indicated that consistent application is rare, with many describing usage as largely voluntary or minimal. The private sector demonstrates only marginally better integration, yet a substantial portion still treats climate scenarios as optional. Non-profit sector respondents presented an even more negative view, emphasizing that consistent application is largely absent and most usage remains minimal or discretionary. This consensus across

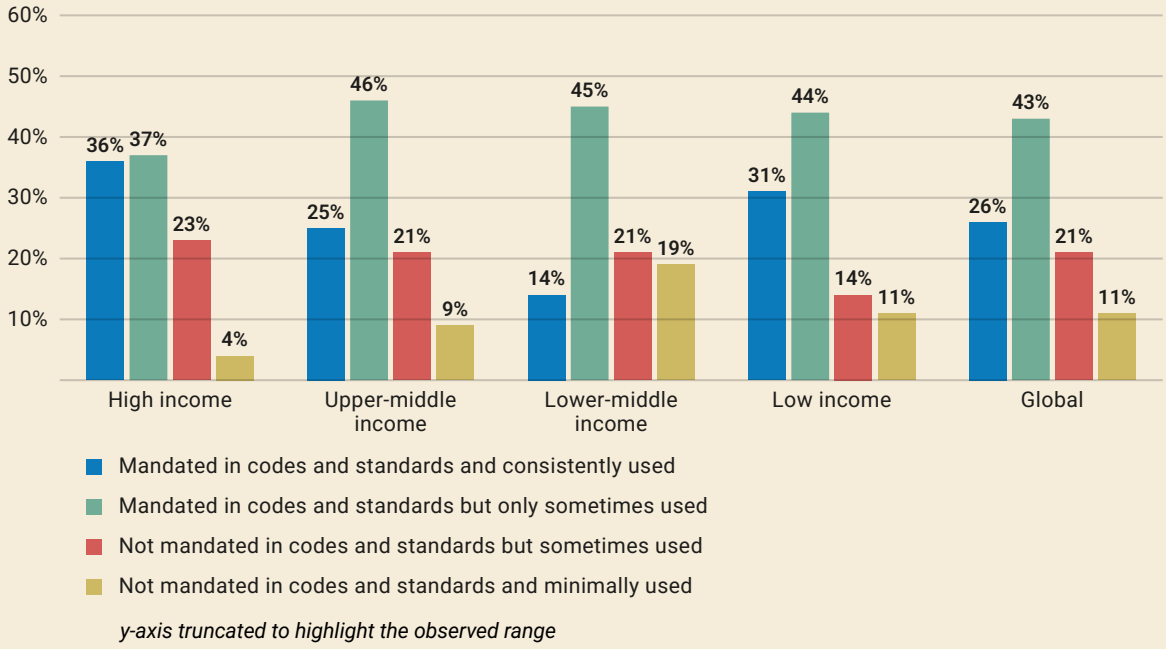


Figure 45

Inclusion of hazard and risk assessments in the design of new and retrofit infrastructure assets, by country income level

Source: Authors' analysis

stakeholders confirms that climate integration remains aspirational rather than operational in most contexts.

Perceptions of climate and disaster risk assessments reveal uneven integration across vulnerability contexts. In both high- and low-vulnerability countries, mandated and consistent use of hazard and risk assessments is relatively more common, while moderate-vulnerability countries show weaker adoption. Climate risk scenarios show even lower levels of integration, with consistent application rare across all contexts and particularly limited in moderate-vulnerability settings. Several respondents described inconsistent or ad hoc use, and many noted non-mandated application. Overall, both climate and disaster risk assessments were seen as only partially embedded in infrastructure planning and practice.

Country income level analysis

The relationship between country income level and risk assessment implementation reveals unexpected patterns that challenge conventional assumptions about resource availability and technical capacity (**Figures 45 and 46**).

About 14 percent of respondents from high-income countries reported weak performance in climate scenario integration, while 17 percent reported that consideration of climate scenarios in infrastructure design is mandated in codes and standards. Expert interviews provide additional context: While some jurisdictions are equipped with systematically embedded climate scenarios through national rainfall and run-off guidance updated with projections, building and fire codes revised using future climate data, and protocols mainstreaming climate considerations, many continue to rely on outdated baselines (International Code Council, 2021). In certain countries, national standards employ outdated hydrology, and building codes exclude future climate data despite its availability. Even where tools exist, such as climate projection platforms, they often remain disconnected from actual design practice.

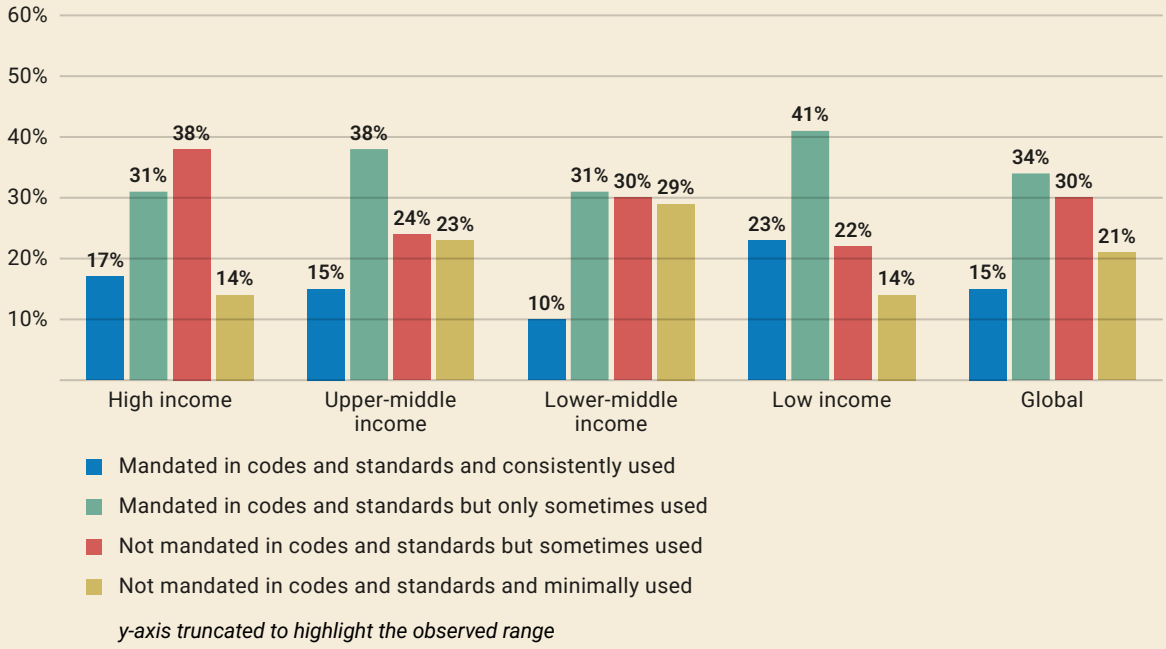


Figure 46

Consideration of future climate risk scenarios in the design of new and retrofit infrastructure assets, by country income level

Source: Authors' analysis

Questionnaire responses from lower-middle-income countries highlight the most acute challenges, with only 14 percent reporting consistent mandated use of risk assessments and just 10 percent noting the same for climate scenarios—the lowest share across all income groups. The interviewed experts confirmed systematic gaps: Assessments are generally donor-driven or restricted to high-risk sectors, leaving most infrastructure projects without integrated climate or hazard considerations. In some cases, cyclone and hydrology assessments are applied in donor-funded projects, but environmental impact assessments are inconsistent, and seismic or flood maps are used only selectively. Experts noted that risk modelling rarely appears in codes and is only partially applied in sectors recently exposed to disasters.

Respondents from low-income countries perceived notable consistency: 31 percent indicated consistent mandated use of risk assessments, and 23 percent noted the same for climate scenarios—the highest level of climate integration reported across all income groups. This pattern is likely influenced by donor requirements shaping assessment practices. Expert interviews reveal that while assessments are referenced in environmental frameworks and occasionally integrated through external support, capacity limitations make systematic application nearly impossible. Risk modelling remains almost absent from codes and standards, and infrastructure design rarely incorporates hazard assessments except in isolated donor projects.

Questionnaire results from upper-middle-income countries show mixed progress, with 46 percent of the respondents reporting inconsistent application of mandated risk assessments. Expert interviews highlight deeper challenges. While risk assessments may be legally required for public investment projects, implementation remains uneven. For example, national investment laws may mandate drought and seismic assessments in building regulations, and climate risk planning may be legislated, yet these requirements often apply only to donor-financed projects or specific sectors. Design processes sometimes incorporate hazard data into seismic codes or coastal modelling, but resilience considerations remain restricted to high-risk assets.

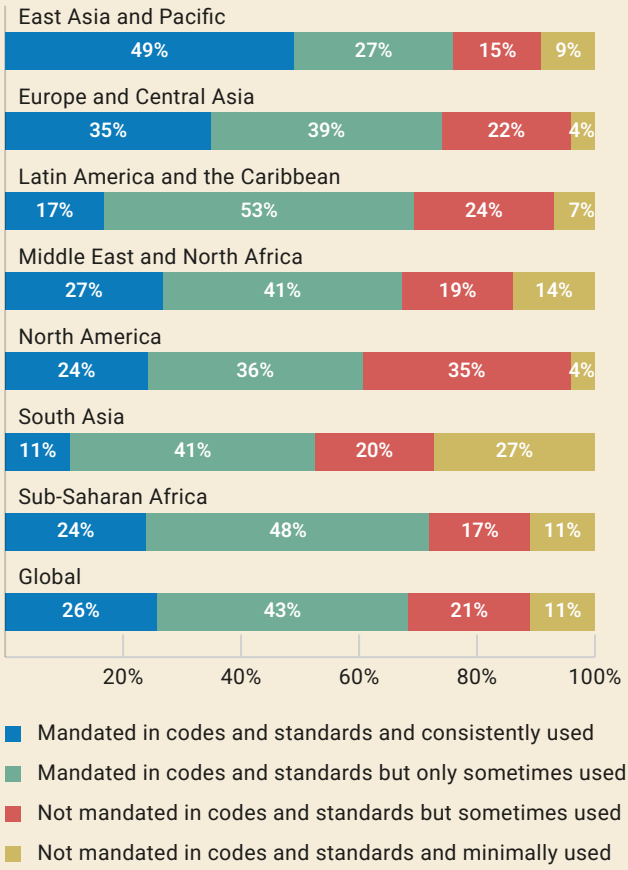


Figure 47

Inclusion of hazard and risk assessments in the design of new and retrofit infrastructure assets, by GIR 2023 region

Source: Authors' analysis

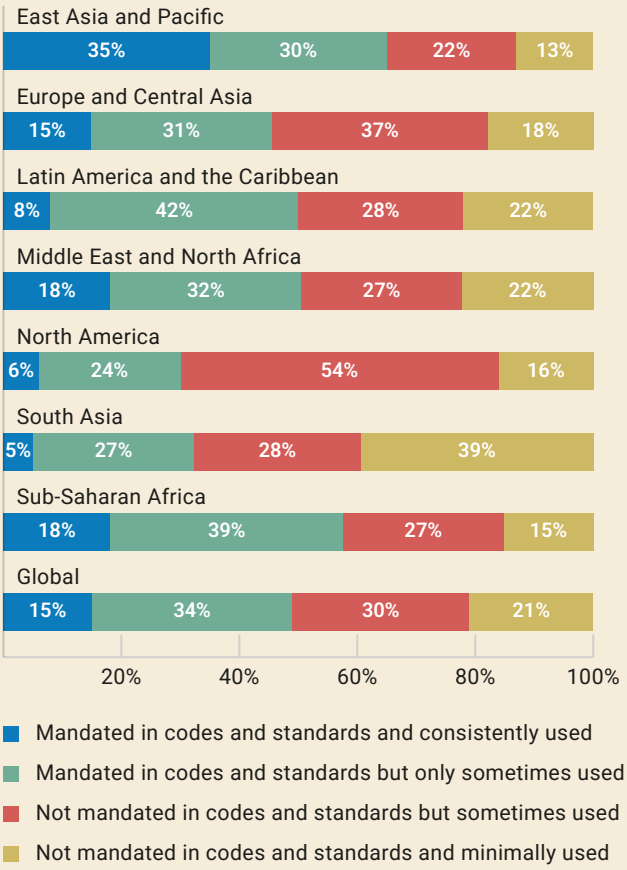


Figure 48

Consideration of future climate risk scenarios in the design of new and retrofit infrastructure assets, by GIR 2023 region

Source: Authors' analysis

Regional analysis

Regional patterns reveal that geography, hazard exposure, and institutional traditions shape risk assessment practices more strongly than income alone (**Figures 47 and 48**).

The East Asia and Pacific region emerges as the clear leader, with 49 percent of the respondents reporting consistent application of mandated risk assessments and 35 percent noting the same for climate scenarios—the highest share of responses globally. Expert interviews and perspectives provide additional context. Strong hazard management traditions in high-income jurisdictions support this performance.

Seismic and tsunami hazard maps guide planning, national climate risk mapping informs decisions, mandatory assessments accompany infrastructure approvals, and design standards embed scenarios for drainage, housing, and coastal protection. Some jurisdictions have even designed major infrastructure projects for 2100 climate scenarios. However, lower-income countries in the region have much weaker integration, with risk assessments largely limited to donor-financed projects and reliance on post-disaster planning rather than proactive assessment. The interviewed experts highlighted the gap between available tools and actual design practice and cautioned against potential optimism bias in the reported results.

The South Asia region presents the weakest picture globally: Only 11 percent of the respondents cited consistency in mandated use of risk assessments, and only 5 percent for climate scenarios. The interviewed experts underscored fundamental capacity constraints, limited technical resources, and systematic gaps in integrating forward-looking risk considerations with infrastructure planning. This confirms that the survey responses reflect broader structural challenges rather than isolated project-level issues.

Latin America and the Caribbean have significant enforcement gaps, with 53 percent of the respondents stating that assessments are mandated but applied irregularly. Expert interviews indicate that although risk assessments may be legally required and seismic codes applied in construction, implementation is often ad hoc or donor-driven, with little systematic uptake across ministries. Climate scenarios remain largely outside mainstream planning despite the existence of national commitments and donor-supported platforms. The interviewed experts noted that reliance on historical hazard data and omission of climate projections in engineering guidelines limit the application of forward-looking resilience strategies.

The Europe and Central Asia region demonstrates relatively strong adoption of risk assessments, with 35 percent of the respondents reporting consistent use, but climate integration remains challenging. Interviewed expert perspectives reveal a divide. Some countries mandate assessments through robust legal frameworks supported by hazard maps and modelling tools, including seismic assessments for schools and hospitals, flood infrastructure standards, and the incorporation of hazard data into transport projects. Others have weak or optional mandates, with inconsistent application. The interviewed experts also highlighted wide variation in climate scenario integration, from systematic embedding in dyke standards and mandatory use in rail and nuclear projects to continued reliance on historical hazard curves and lack of codification.

In North America, formal requirements exist at the federal level, supported by climate assessment frameworks and hazard mitigation protocols, yet only 24 percent of the respondents reported consistent mandated use; 35 percent of the respondents stated that assessments are not mandatory, though they are sometimes used, reflecting a reliance on voluntary practices. Climate scenario integration is uneven, with some jurisdictions embedding scenarios in assessments, design, and codes via revised building standards and protocols, while others continue to use historical baselines despite federal recognition of future risks. The interviewed experts emphasized that local governance and institutional priorities drive these differences.

The Sub-Saharan Africa region shows emerging but fragmented progress. Some countries mandate inclusion of assessments through climate legislation and environmental frameworks, incorporating hazard components into impact assessments. The interviewed experts highlighted that design occasionally uses hazard data for drainage, coastal protection, or stormwater systems, but not systematically. Climate scenarios remain largely absent—except for isolated applications of 20- to 50-year projections in high-profile projects—with codes rarely embedding projections. Experts underscore the role of donor support in driving these isolated applications, noting that capacity limitations constrain systematic uptake.

The Middle East and North Africa region shows mixed integration. High-capacity hubs in higher-income settings apply assessments systematically through transport adaptation strategies and hazard datasets for infrastructure

planning; elsewhere, application remains partial and inconsistent. Interviewed expert perspectives reveal that while climate scenarios are recognized, they are rarely embedded systematically in planning, design, or standards. Experts indicated that differences in institutional capacity and sectoral focus explain much of the regional variation.

Discussion

These findings reveal a global disconnect between policy ambition and implementation. While most countries mandate risk assessments, the gap between policy and practice remains substantial. Integration of climate scenarios is even weaker. Infrastructure is designed primarily using historical data, ignoring the changing hazard patterns. Without stronger incorporation of both current and future risk considerations, countries' assets will be vulnerable to climate change and disasters.

The stronger mandated use reported in some low-income countries is largely in response to donor-driven requirements. In high-income countries, voluntary, market-driven approaches result in inconsistent coverage. Across all contexts, reliance on historical data rather than future projections limits the alignment of infrastructure investment with evolving climate realities, even where sophisticated tools are available.

Regional differences indicate that disaster experience and hazard exposure influence the uptake of risk assessments. However, even in regions with strong disaster management capabilities, forward-looking climate considerations remain limited.

Box 6

Case study: Institutionalizing climate and disaster risk in development planning in Colombia

Colombia has institutionalized the use of both climate and disaster risk assessments at national and local levels. The country's National Disaster Risk Management Unit (Unidad Nacional para la Gestión del Riesgo de Desastres & INGENIAR: Risk Intelligence, 2018) published the Colombian Risk Atlas: Revealing Latent Disasters in 2018, which provides multi-hazard probabilistic maps for earthquakes, floods, and other disasters, supporting decision-making at both national and local scales. More recently, the National Disaster Preparedness Baseline Assessment, developed with the Pacific Disaster Center (PDC, 2025), has offered hyper-local, municipality-level risk insights for 11 hazard types, accessible via PDC's digital platform, DisasterAWARE (PDC, 2025).

At the same time, Colombia's 2050 Long-Term Climate Strategy (E2050) (Gobierno de Colombia, 2021) sets out pathways for carbon neutrality and climate resilience, explicitly incorporating future climate scenarios, alongside complementary tools such as the Colombian Carbon Calculator 2050 (IDOM, 2023). This tool models four alternative futures using 29 mitigation measures across energy, transport, agriculture, and other sectors. This scenario-based approach enables policymakers to evaluate cross-sectoral risks, trade-offs, and synergies under different climate trajectories.

Importantly, under Law 1523 of 2012 and subsequent decrees, municipalities are legally required to incorporate disaster risk analysis into their land-use plans (Planes de Ordenamiento Territorial), ensuring that hazard zones are formally recognized in planning instruments (World Bank, 2021a). Collectively, these instruments demonstrate Colombia's strong legal and institutional framework for embedding climate and disaster risk within development planning.

Box 7

Case study: Integrating 2100 climate scenarios with the Melbourne Metro Rail Project, Australia

The Melbourne Metro Rail Project exemplifies proactive climate adaptation in urban infrastructure. The project integrates climate resilience by incorporating future climate scenarios up to the year 2100. A key component of this approach is the Surface Water Impact Assessment report dated April 2016 (Melbourne Metro Rail Authority, 2016), which evaluates potential flooding risks from various sources, including Maribyrnong River, Moonee Ponds Creek, and local drainage systems. This assessment informs design modifications to mitigate these risks, ensuring that infrastructure remains functional and safe amid the projected climate changes. The project also considers factors such as the increased frequency of extreme-weather events, rising temperatures, and potential flooding risks, adjusting structural components and drainage systems accordingly. This forward-thinking strategy not only enhances the resilience of the rail network but also sets a benchmark for future infrastructure projects to adapt to long-term climate variability.

5.2 Data Availability

High-quality and accessible data on hazards, exposure, vulnerabilities, and asset conditions is essential for engineers, planners, and decision-makers to identify risks, prioritize interventions, and design infrastructure capable of withstanding future shocks. However, many countries, particularly low- and middle-income economies, face significant gaps in climate, geospatial, and asset data, as well as in the capacity to analyse and utilize this information effectively.

Addressing these gaps requires coordinated data collection, standardization, and dissemination across agencies and sectors (UNDRR, 2023). Accessible, standardized datasets not only improve the technical quality of risk assessments but also build investor and insurer confidence by making risks more transparent and comparable.

KEY FINDING 9

Global data for infrastructure hazard, vulnerability, and risk assessments is limited and uneven. Only 16 percent of the respondents noted comprehensive coverage, while 43 percent cited insufficient data and partial or inconsistent application, and 10 percent reported no data availability at all. Challenges include accessibility, interoperability, and usability. Institutional silos, poor data quality, and political and bureaucratic constraints affect all country income levels and regions, undermining evidence-based resilience planning.

Global trends

Respondents' views on data availability for infrastructure hazard, vulnerability, and risk assessments indicate that comprehensive datasets are rare, with only 16 percent reporting complete coverage globally. The largest share of respondents (43 percent) indicated limited data, sufficient only for partial or inconsistent assessments, while 10 percent perceived no data availability at all. Expert interviews suggest that even where data exists, accessibility, quality, and interoperability remain persistent challenges across all country income levels and regions.

These limitations are consistent across infrastructure sectors and all stakeholder groups. Data for infrastructure resilience is largely incomplete and inconsistent. Comprehensive data was reported by only 16 percent of the respondents, while the majority cited moderate, partial coverage. Moderate-vulnerability countries appear the most disadvantaged, with just a tenth reporting comprehensive datasets and over half noting fragmented access. Approximately 10 percent of the responses in every context indicate no data availability, underscoring widespread gaps that hinder effective planning and decision-making.

This consistency across regions, sectors, and stakeholder groups signifies that data challenges are systemic rather than confined to specific contexts. While responses from the private sector suggest marginally better access, serious limitations are widely acknowledged across both the buildings sector and other infrastructure sectors, and among public and private stakeholders alike.

Country income level analysis

Data availability patterns across country income levels reveal unexpected disparities—with middle-income countries facing the greatest constraints—rather than following a simple wealth gradient (**Figure 49**).

Lower-middle-income countries experience the most severe data limitations. Only 10 percent of the respondents from these countries reported comprehensive availability (the lowest globally), while 53 percent described data as limited, and 17 percent perceived no availability at all. Expert interviews indicate that although hazard datasets exist, they are incomplete, poorly maintained, or not downscaled for local planning. Agencies produce data, but localized hazard and exposure information is lacking; strong hydrological data exists, but agencies are reluctant to share it; and hazard data does not have the local granularity needed for infrastructure planning. As one expert noted, "Access to data in our country, I must say, is a bit difficult … most of the data you have to buy from the Department of Meteorology."

Respondents from high-income countries describe relatively robust systems, with 43 percent reporting moderate data availability. However, expert interviews reveal significant underlying challenges despite the abundance of data. Countries maintain extensive hazard mapping and open-data platforms but often struggle with integration and gaps in future-oriented information. Common issues include the following: abundant open datasets but weak capacity to use them, climate projection data available but limited on extremes, extensive hazard mapping but weak integration of climate projections, and poor interoperability between rainfall, seismic, and asset systems. Barriers include siloed sectors, outdated datasets relying on century-old hazard curves, a lack of asset vulnerability data, and institutional reluctance to share information.

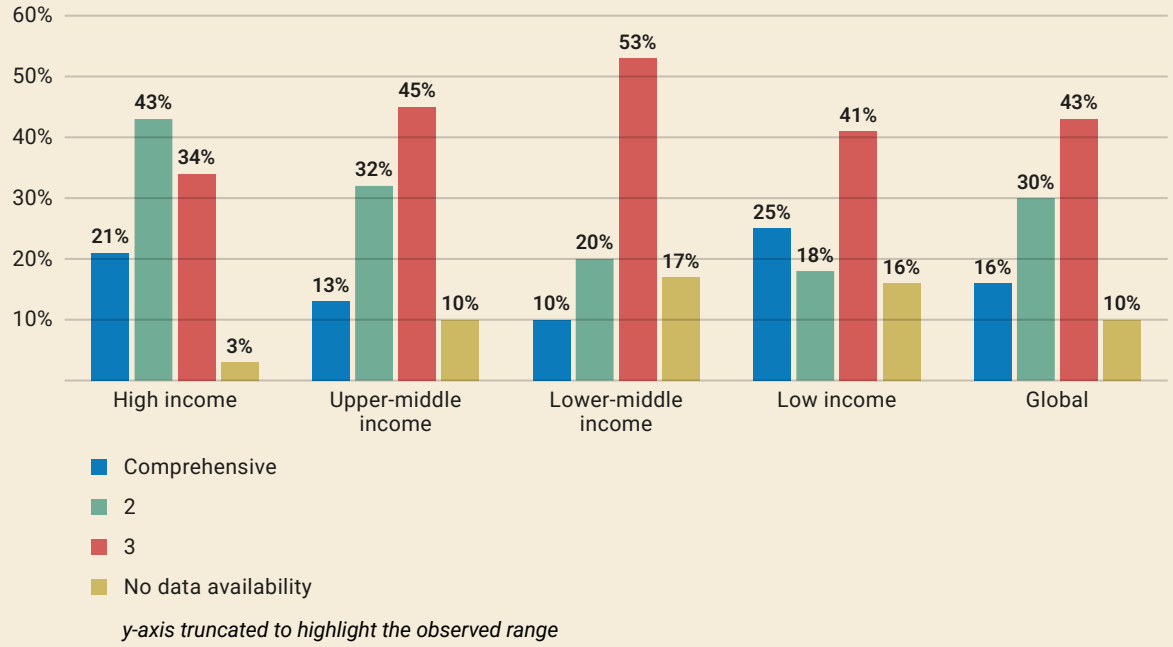


Figure 49

Availability of data for infrastructure hazard, vulnerability, and risk assessments, by country income level

Source: Authors' analysis

The surprising number of positive responses from low-income countries, where 25 percent of the respondents reported comprehensive data (the highest share overall), likely reflects targeted international support—though 41 percent still noted limited data availability. Expert interviews reveal that data is usually available but is scattered, with limited historical coverage and weak resolution. Most data is at a global or national scale and is thus unsuitable for local infrastructure planning. Historical weather data may exist but only covers recent decades, while hazard and climate data scattered across institutions lack downscaling and are hard to access.

Responses from upper-middle-income countries lag behind expectations, with only 13 percent reporting comprehensive coverage and 45 percent describing data as limited. Expert interviews reveal that data is usually available but is unevenly accessible; fragmentation and weak interoperability are major issues. While some countries have central agencies managing hazard and disaster data, processes are often slow and technical capacity is limited. Common barriers include lack of resources, political reluctance to share data, poor maintenance of monitoring systems, and bureaucratic restrictions limiting accessibility. As one expert explained, "We made certain data publicly available in real time, but bureaucracy and recommendations to sell data created barriers to access and use."

Regional analysis

Regional patterns reveal how institutional traditions and governance approaches shape data availability as much as technical capacity or resources (**Figure 50**).

Respondents from the East Asia and Pacific region led with 28 percent reporting comprehensive data, though expert interviews reveal persistent integration challenges. Many countries maintain strong hazard datasets, but integration of climate projections and interoperability remain weak. High-income countries in the region often have extensive data but incomplete coverage for emerging risks. Other issues include the following: hazard mapping is strong, but climate integration is weak; accessible projections lack spatial overlays for future hazards; and some datasets are confidential. Lower-middle-income contexts face additional barriers such as inadequate data sharing and resolution.

Respondents from South Asia had the weakest outlook, with 56 percent describing data as limited (the highest share globally) and only 9 percent citing comprehensive availability. This aligns with expert interviews revealing fundamental gaps in data infrastructure and sharing mechanisms.

Results from Latin America and the Caribbean show similar constraints, with only 9 percent of the respondents citing comprehensive coverage and 48 percent reporting limited data. Expert interviews reveal a gap between data availability and accessibility. Hazard and climate datasets generally exist but are fragmented and inconsistently shared. Central agencies may manage disaster data, but weak interoperability, bureaucratic restrictions, and siloed ministries limit access. Vandalization of monitoring stations, costly databases, and withholding of critical data, such as LiDAR, further restrict usability.

Respondents from Europe and Central Asia gave better than average ratings, with only 3 percent indicating no data availability (the lowest globally), although 38 percent described data as limited. Expert interviews reveal that strong data platforms and hazard databases exist, but challenges persist in harmonization and integration. Some countries provide highly accessible datasets through open climate effect atlases. Other countries face fragmentation, with abundant hazard data but gaps in the vulnerability of old assets, large datasets but inconsistent methodologies, accessible rainfall and seismic data but no integration with asset systems, and outdated hazard curves despite the availability of technology.

Results from Sub-Saharan Africa show systemic gaps, with 48 percent of the respondents describing data as limited. Expert interviews indicate that data availability has improved, with some countries developing national hazard platforms, but accessibility remains weak and awareness limited. Technical capacity and dissemination are major barriers; hazard datasets are available but poorly used by practitioners, meteorological data is costly rather than freely accessible, and data is scattered across institutions without downscaling for local use.

Responses from North America show a stable middle ground, with 52 percent describing moderate availability. Expert interviews, however, reveal surprising gaps. Despite high data availability, hazard coverage is incomplete, with gaps in flood mapping, missing wildfire data, fragmented ownership, and reliance on outdated empirical hydrology. Weak local capacity to interpret the available data emerges as a key barrier.

Results from the Middle East and North Africa show mixed patterns. Some high-income hubs provide multi-hazard datasets, but access is inconsistent and

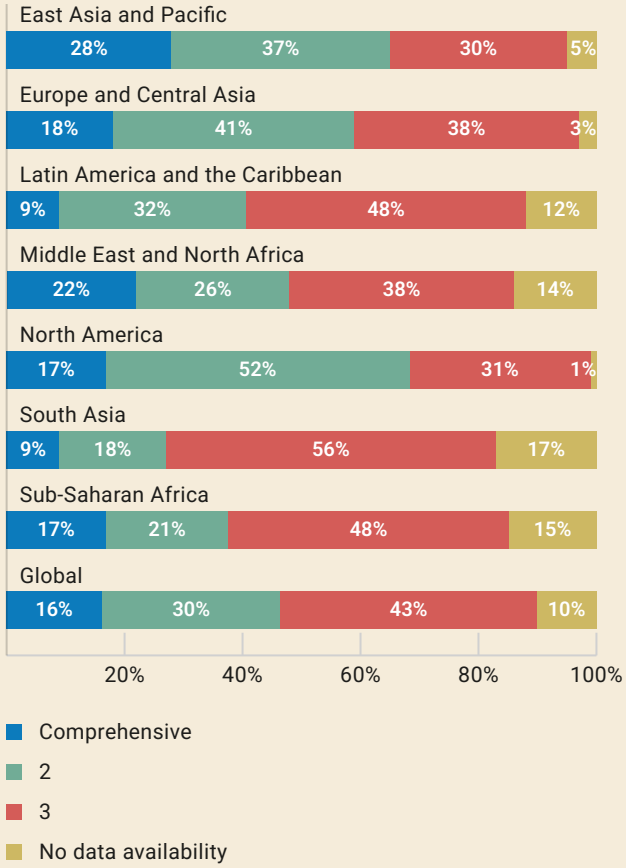


Figure 50

Availability of data for infrastructure hazard, vulnerability, and risk assessments, by GIR 2023 region

Source: Authors' analysis

depends on institutional willingness to share. Comprehensive datasets exist but may be offset by reluctance to share and poor awareness among public officials. In other contexts, data is limited and fragmented with no centralized platform.

Discussion

Global data challenges extend beyond mere availability to issues of accessibility, interoperability, and usability. Across contexts, data often exists but is trapped in institutional silos, suffers from poor quality or incompatible formats, or is restricted by political and bureaucratic limits. High-income countries struggle with integration despite having sophisticated datasets, while low-income countries face gaps in coverage and resolution. Middle-income countries experience both fragmented datasets across multiple agencies and insufficient resources to integrate them. Political reluctance to share, monetization of data, and inter-agency competition further limit access. Additionally, most data is too coarse for local infrastructure planning, and the resources needed to downscale are often unavailable (World Bank, 2021c). Ensuring mandated sharing, standardized formats, sustained monitoring, and capacity-building is essential to produce complete risk assessments and support evidence-based resilience planning.

Box 8

Case study: The KlimaatEffectAtlas, Netherlands

The KlimaatEffectAtlas, managed by Climate Adaptation Services (n.d.) and commissioned by the Dutch Ministry of Infrastructure and Water Management, is a distinctive open-data digital platform presenting highly detailed climate risk maps, ranging from heat and drought to flooding and waterlogging. Its interactive map viewer delivers maps at up to 2-metre resolution, offering granular insights, while the neighbourhood dashboard distils this detail into accessible summaries for local planning and comparative analysis. All data is openly downloadable in geographical information system (GIS) formats under a Creative Commons licence, enabling reuse and transparency. As a collaborative effort, including public agencies, academia, and consultants, the platform promotes interdisciplinary engagement and standardized risk data sharing across stakeholders.

By combining high-resolution geospatial visualization with accessible tools and open licensing, the KlimaatEffectAtlas is a compelling example of good practice in enabling evidence-based climate and disaster risk assessments.

6. Use of Advanced Technologies to Enhance Infrastructure Resilience

Advanced technologies such as predictive analytics, satellite imagery, digital twins, sensor technologies, and new materials can enable data-driven, evidence-based decision-making to embed resilience across the entire infrastructure life cycle.

The research looked into the role of innovation in strengthening resilience across infrastructure systems through the adoption of advanced technologies and investigated the systemic barriers that prevent their wider mainstreaming.

KEY FINDING 10

Globally, advanced technologies for infrastructure resilience are mostly limited to flagship projects, with 51 percent of the respondents stating they are used selectively and just 12 percent reporting consistent use. Adoption is driven more by institutional, regulatory, and governance factors than by technical capacity. Barriers include fragmented oversight, weak mandates, funding limits, and uneven local expertise. Without systemic integration, most infrastructure systems still have to rely on traditional approaches to strengthen resilience.

Global trends

Globally, advanced technologies are recognized and showcased but rarely deployed widely. Survey results show that advanced technologies are primarily applied in a few high-profile projects, with 51 percent of the respondents reporting selective use and only 12 percent noting consistent integration. Patterns are similar across sectors: Less than half of the buildings sector respondents reported selective use, while more than half of the other infrastructure sectors respondents noted the same. Stakeholder views are aligned among government, the private sector, academia, not-for-profits, and financial institutions: Across all contexts, selective use of advanced technologies dominates, while consistent use is especially low in moderate-vulnerability countries.

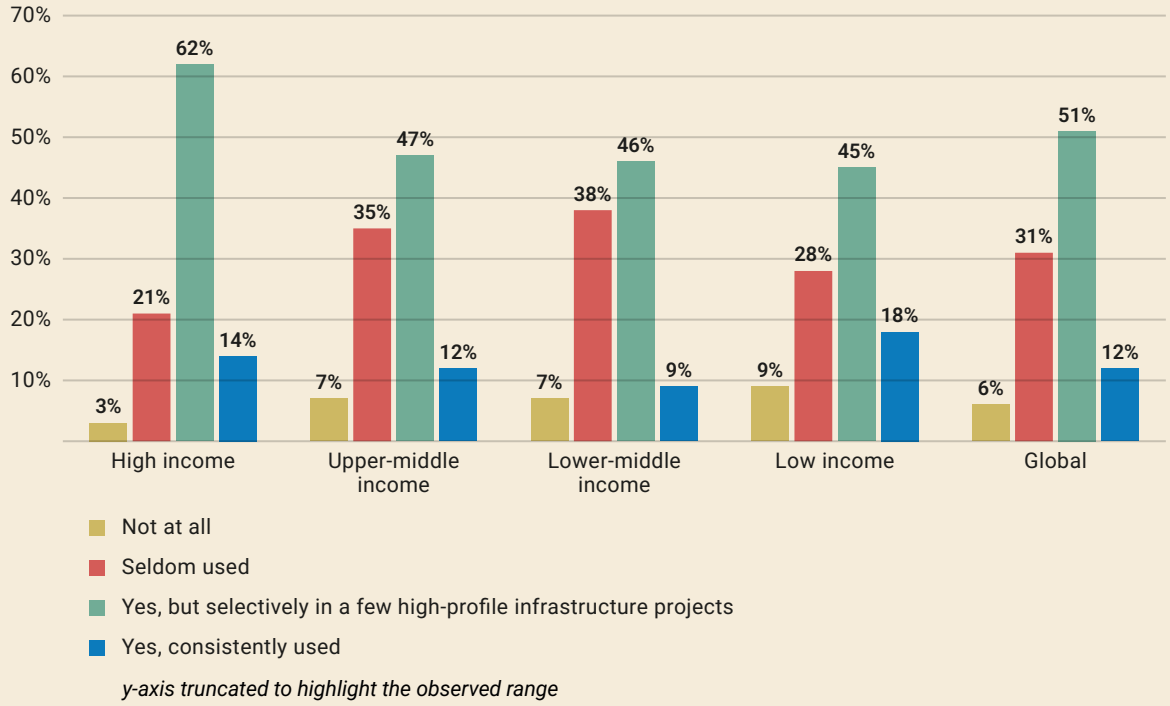


Figure 51

Use of advanced technologies to strengthen the resilience of infrastructure assets and systems, by country income level

Source: Authors' analysis

Country income level analysis

The relationship between income and technology adoption reveals patterns that do not align neatly with resource availability or innovation capacity (**Figure 51**).

Respondents from high-income countries perceive fairly strong adoption, with 14 percent reporting consistent and 62 percent noting selective use. This indicates greater institutional and technical capacities and availability of resources (OECD, 2024). Expert interviews confirm widespread deployment of sensors, drones, digital twins, predictive modelling, and artificial intelligence (AI)–based platforms across the transport, energy, water, and buildings sectors. Examples include supervisory control and data acquisition (SCADA) systems, real-time hazard alerts, climate-informed building codes, monitoring systems in transport and energy networks, predictive analytics and digital twins in rail systems, comprehensive use of building information modelling (BIM), Internet of Things (IoT), and robotics.

In upper-middle-income countries, 47 percent of the respondents reported selective use and 35 percent rare use. Technologies are occasionally deployed—often in pilots or donor-driven projects—but not systematically embedded. Examples include GIS and early-warning systems, flood modelling and satellite data, telemetric monitoring, aquifer sensors, smart bridge sensors, clean-tech in buildings, and portable solar and storage initiatives. Barriers are mainly institutional and financial: lack of coordination and oversight, weak regulatory frameworks, dependence on donors and consultants, unstable budgets, cultural preference for traditional materials, and vandalism of equipment.

Respondents from lower-middle-income countries indicated the weakest diffusion, with 38 percent reporting limited uptake. Uptake is growing in selected areas—typically donor-supported—particularly in urban centres and high-risk locations. Examples include IoT and drones for early warning, satellite imagery, and sensors, though systematic use remains limited. Barriers include weak technical capacity, absence of mandates and legislation, limited financing, and reliance on donors.

Results from low-income countries show interesting contrasts: 45 percent of the

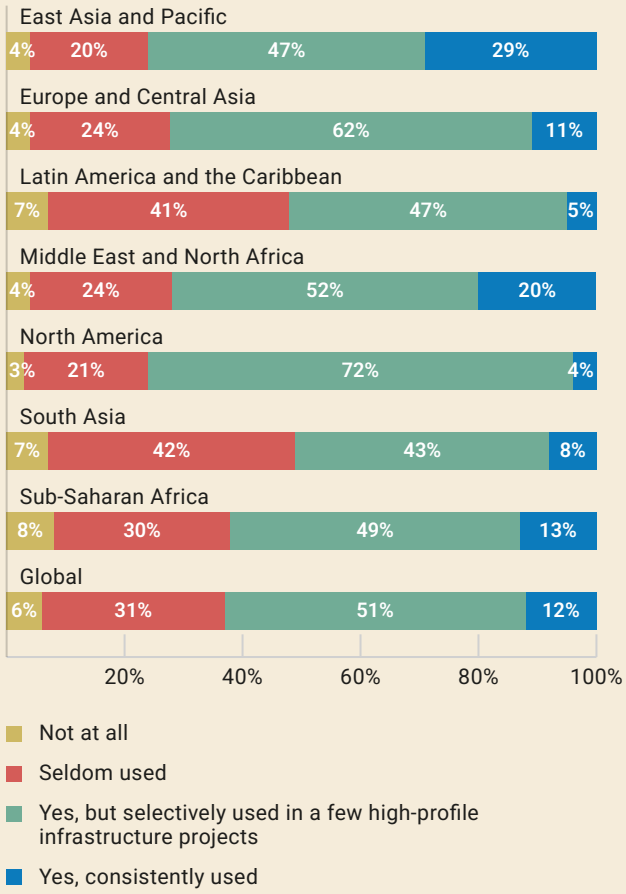


Figure 52

Use of advanced technologies to strengthen the resilience of infrastructure assets and systems, by GIR 2023 region

Source: Authors' analysis

respondents reported selective use—second only to high-income contexts; 18 percent noted consistent use, and 9 percent perceived no use at all—the highest percentages globally. Expert interviews indicate that adoption is often supported by development partners but is limited in scope and scale. Examples include sensors, GIS, hydrological modelling, real-time monitoring systems, traffic management, and flood mapping. Barriers include high costs, limited technical skills, uneven institutional capacity, lack of predictive analytics, and weak uptake beyond capital cities (World Bank, 2023).

Regional analysis

Regional patterns show that institutional traditions and governance approaches shape technology adoption as much as technical capacity (**Figure 52**).

Respondents from the East Asia and Pacific region led globally, with 29 percent reporting consistent application. However, caution should be exercised regarding the robustness of these outcomes due to the potential for optimism bias in this region. High-income countries in the region demonstrate advanced integration of BIM, AI, digital twins, SCADA systems, drones, AI hazard modelling, and digital twins for sea-level rise planning. Lower- and middle-income contexts show weaker adoption, limited to isolated use. Barriers include funding shortfalls, weak mandates, siloed ministries, integration gaps, and insufficient data for advanced analytics.

In North America, only 4 percent of the respondents reported consistent use despite the existence of advanced capabilities, and 72 percent identified selective application in flagship projects. Technologies are adopted across sectors—modelling, updated codes, electrification, and backup power—but uptake is uneven. Barriers include funding shortfalls, fragmented implementation across jurisdictions, bureaucratic and permitting delays, and community resistance.

Results from Latin America and the Caribbean show low diffusion: 5 percent of the respondents reported consistent integration, and 41 percent stated that technologies were seldom used. Technologies such as GIS, early-warning systems, satellite data, telemetric aquifer monitoring, mobile risk tools, and sluice gate automation are used sporadically. Barriers include governance fragmentation, lack of follow-up on pilots, limited funding, preference for grey infrastructure, and no mandates.

Responses from Europe and Central Asia display selective patterns, with 62 percent indicating selective use and 11 percent consistent integration. Technologies used include digital twins, smart roads with advanced materials, predictive analytics, scenario modelling, wildfire-monitoring drones, and monitoring networks. Barriers are high implementation costs, regulatory inertia, institutional fragmentation, lack of national strategies, and uneven regional expertise.

In Sub-Saharan Africa, 30 percent of the respondents reported rare use and 8 percent no use—the highest globally. Some adoption exists, with the use of sensors, GIS, IoT, drones, radar and buoy systems, and GIS-based modelling. Barriers include weak technical expertise, funding constraints, reliance on donors, preference for traditional construction, and limited uptake beyond capital cities.

Responses from the Middle East and North Africa show modest uptake, with 20 percent indicating consistent use. High-income hubs use city digital twins and BIM, but adoption is scattered elsewhere. Barriers include gaps in skills, weak local expertise, lack of mandates, low prioritization of resilience, and predominance of small-budget firms.

Discussion

These findings show that technology adoption for resilience is constrained by factors beyond mere resource availability. Selective application in flagship projects across all regions and country income levels indicates that the main challenge lies in integrating technologies systematically with standard practice (OECD, 2018).

The limited uptake in high-income countries, despite their strong technical capacity, signifies that institutional and financial barriers are greater constraints than the technology itself. Even where advanced tools are deployed, they remain confined to specific sectors or high-profile projects. The frequent observation that “there is not enough money to make things resilient” reflects misaligned priorities rather than absolute resource limits.

The stronger adoption in some low-income countries illustrates both potential and risk. Donor support can catalyse uptake, but reliance on external expertise and funding undermines sustainable capacity (World Bank, 2021b). Technologies often operate in capitals but fail to reach other areas, emphasizing the need for local technical capacity.

Institutional barriers consistently outweigh technical hurdles. Fragmented governance, siloed ministries, weak regulatory frameworks, the absence of clear mandates, and rigid procurement processes prevent scaling from pilots to broader adoption. Cultural preferences for traditional materials and resistance to new approaches further limit uptake (World Economic Forum, 2016).

Unless these barriers are addressed through integrated governance, sustained funding, local capacity-building, and regulatory mandates, advanced technologies will remain confined to flagship projects while most infrastructure continues to rely on outdated approaches.

7. Nature-based Solutions

NbS in the context of resilient infrastructure refer to measures that leverage nature and ecosystems to reduce the vulnerability of infrastructure assets or populations to natural hazards. This section presents the responses to the survey questions regarding the uptake and implementation of NbS to strengthen infrastructure resilience.

KEY FINDING 11

NbS remain largely confined to pilots, with only 15 percent of the respondents reporting systematic use and 44 percent perceiving sporadic application. Key barriers include inadequate financing and maintenance, limited inclusion in codes and standards, and gaps in professional capacity. Without addressing these constraints, NbS cannot scale beyond donor-dependent projects to mainstream resilient infrastructure.

Global trends

Results from the study reveal that awareness of NbS is growing, yet adoption remains uneven and largely project-specific. Only 15 percent of the respondents reported systematic application, while 44 percent stated that NbS are used in a few projects, and 25 percent noted rare application. Supporting systems are even weaker: 65 percent of the respondents viewed financing mechanisms as somewhat underdeveloped or not developed at all, and just 8 percent saw them as fully established. Maintenance arrangements and in-house capacity show similar weaknesses, with 62 percent describing in-house capacity and 69 percent describing maintenance as somewhat underdeveloped or not developed at all and less than 10 percent reporting fully operational systems.

Across sectors, adoption patterns are consistent. Systematic use of NbS is slightly higher in the buildings sector than in other infrastructure sectors. Yet in both groups, around a quarter of the respondents perceived limited application in projects.

Stakeholder perspectives are equally aligned across government, the private sector, and non-profits.

Slightly more than one-third of respondents from both the building sector and other infrastructure sectors reported having consistent financing mechanisms and clear maintenance arrangements for NbS. Among government actors, fewer than 1 in 10 indicated that such financial mechanisms and maintenance arrangements were fully developed, while most described them as only partially developed or underdeveloped. Private-sector respondents expressed slightly more optimism, whereas those from academia, not-for-profit organizations, and financial institutions tended to be somewhat more pessimistic.

In-house capacity for planning, implementing, and managing NbS is the weakest area. Only 9 percent of all respondents across sectors and institutions reported fully developed capacity, while 26 percent stated that none exists. The largest number of responses (66 percent) described capacity as partially developed or somewhat underdeveloped, highlighting persistent gaps. Overall, while there are pockets of progress, the adoption, financing, and maintenance of NbS, and institutional capacity remain fragmented and far from systematically embedded across sectors.

Country income level analysis

The adoption of NbS across income groups reveals patterns that challenge assumptions about environmental awareness and capacity.

Respondents from high-income countries perceived the highest adoption, with half of them reporting that NbS are used in a few projects. Expert interviews highlight initiatives such as sponge cities, green corridors, blue-green water management programmes, floodplain restoration, oyster reefs and coastal wetlands, and swales integrated into transport corridors. Some jurisdictions have embedded NbS into codes through green plot ratios or stormwater pond standards. Implementation, however, remains uneven and is often limited to pilots or sector-specific projects. Integration with grey infrastructure is strongest in hybrid water management systems. Barriers include high upfront costs, limited operations and maintenance budgets, siloed expertise, and weak technical capacity among engineers.

Responses from upper-middle-income countries indicated use in a few projects and rare use. NbS remain largely confined to urban drainage pilots, wetland restoration, retention basins, ecological road alignments, green roofs, and bamboo or vegetated slope stabilization. Codes and standards rarely reference NbS, integration with grey infrastructure is minimal, and in-house capacity is limited. Barriers include low awareness, lack of regulatory frameworks, and cultural preferences for conventional solutions, with NbS sometimes dismissed as ‘fashionable’ but impractical.

Lower-middle-income countries face severe constraints, with only a quarter of the respondents reporting use in a few projects and a third citing rare application. NbS are mostly restricted to donor-financed pilots, including watershed management, erosion control, or small-scale projects without long-term budgets. Codes rarely reference NbS, integration with grey infrastructure is largely absent, and ministries rely heavily on NGOs or donors. Barriers include limited financing, weak technical knowledge, and entrenched preferences for conventional solutions with concrete.

Results from low-income countries present a different pattern, with a third of the respondents reporting consistent application; this conflicts with expert

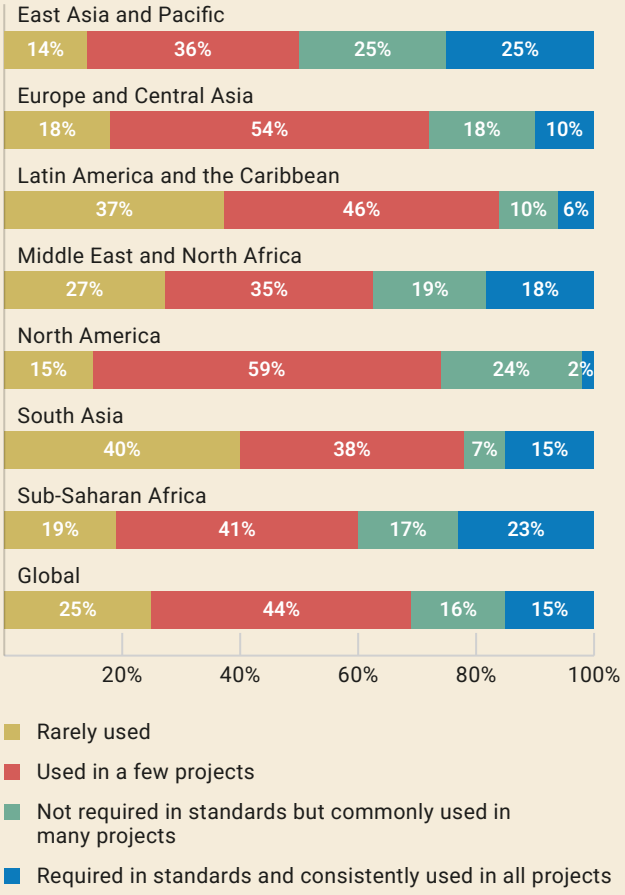


Figure 53

Use of NbS, by GIR 2023 region

Source: Authors' analysis

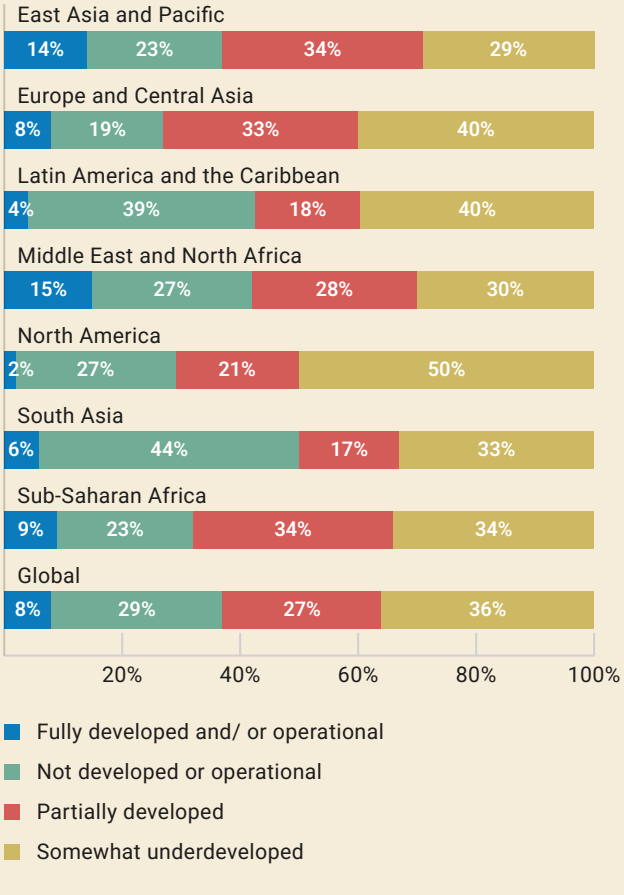


Figure 54

Financing mechanisms for NbS, by GIR 2023 region

Source: Authors' analysis

views reporting few donor-backed pilot projects and low local awareness or capacity to implement and maintain these solutions. Emerging projects include wetlands and slope stabilization, tree planting, and reforestation, though these remain externally driven and small in scale. NbS are absent from codes and rarely integrated with grey infrastructure, and ministries lack technical staff. As one expert noted, "NbS are emerging, but neither public nor private institutions are well prepared in terms of skills and tools."

Regional analysis

Regional patterns indicate that institutional traditions and ecosystem contexts strongly influence NbS adoption (**Figures 53–56**).

Respondents from Sub-Saharan Africa reported consistent use at 23 percent, though 41 percent noted application in only a few projects. Expert interviews highlight the increasing number of pilot projects in drainage, wetlands, and reforestation, including wetland

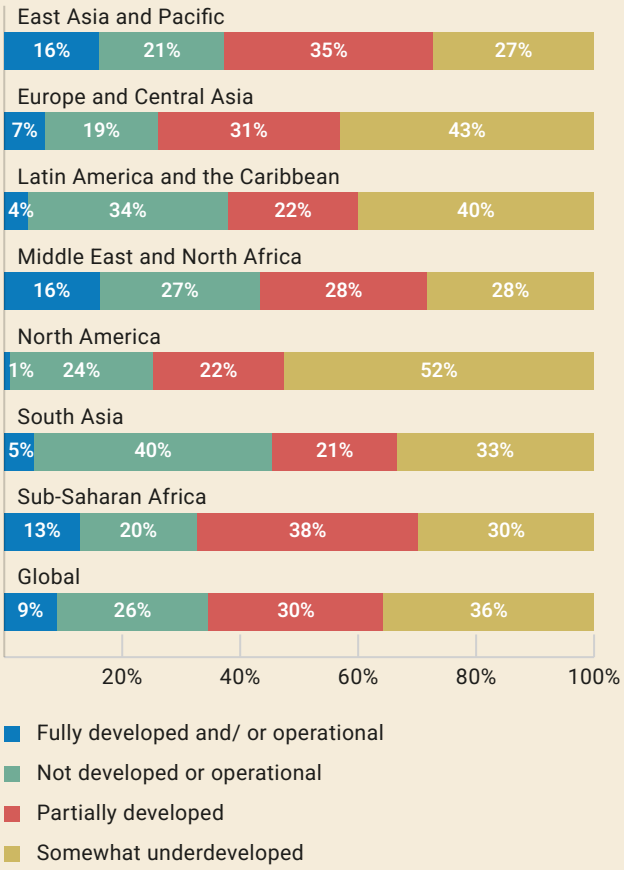


Figure 55

In-house capacity of infrastructure agencies/ministries to plan for, implement, and manage NbS, by GIR 2023 region

Source: Authors' analysis

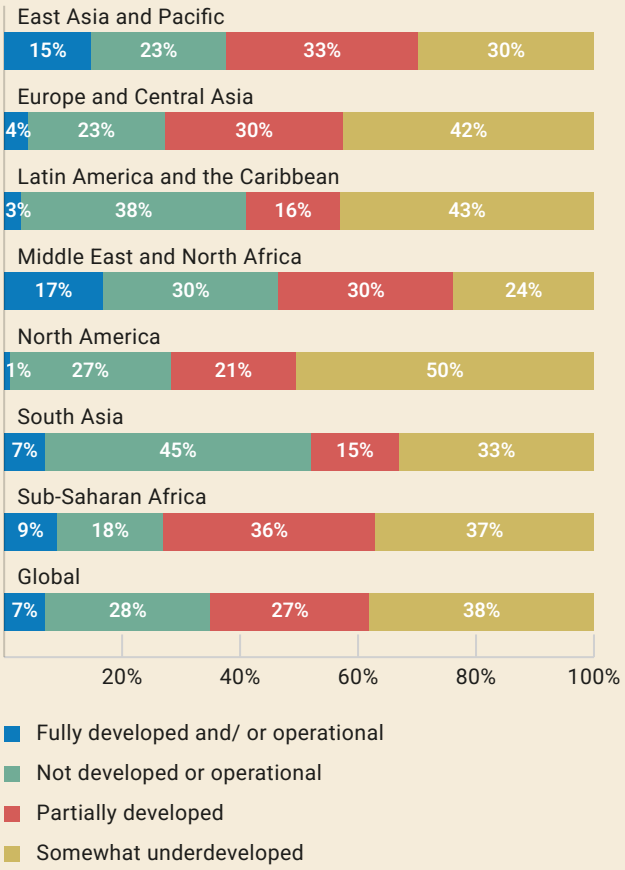


Figure 56

Clarity of maintenance arrangements for NbS, by GIR 2023 region

Source: Authors' analysis

rehabilitation, ecological road design, and erosion control. However, standards exclude NbS, integration with grey infrastructure is inconsistent, and capacity relies heavily on universities and NGOs rather than ministries (Thorn et al., 2021). One expert noted, "NbS are predominantly used in pilots and targeted programmes. Adoption in mainstream large infrastructure projects remains limited."

In North America, only 2 percent of the respondents reported systematic integration despite 59 percent indicating use in specific projects. Expert interviews describe sophisticated applications in flood and coastal resilience—including stormwater pond standards and oyster reef restoration—and strong integration in hybrid coastal projects. Institutional capacity remains uneven, and funding shortfalls limit scaling.

Results from Latin America and the Caribbean show weak systematic adoption, with just 6 percent of the respondents reporting consistent use and 46 percent sporadic application. NbS appear in drainage pilots, watershed projects, and bamboo slope stabilization, with stronger integration in some countries through mangroves and wetlands complementing dams and canals. Standards exclude NbS, ministries lack in-house capacity, and cultural preferences for concrete persist. One expert observed, "Wetlands are restored for their ecological value, but nobody manages them as infrastructure for resilience."

Respondents from Europe and Central Asia reported more advanced but uneven adoption. While 54 percent noted use in a few projects, only 10 percent perceived consistent application. NbS are concentrated in the water sector through sponge cities, green corridors, and hybrid stormwater systems. Integration with grey infrastructure is stronger in water and urban sectors but weaker elsewhere. In-house capacity varies, with some municipalities leading while ministries lack expertise.

Results from the East Asia and Pacific region show split patterns, with 25 percent of the respondents reporting consistent use and 36 percent sporadic uptake. High-income contexts lead, with NbS increasingly mainstreamed and reflected in codes via green plot ratios and integrated water management programmes. Integration with grey infrastructure is advanced in some hybrid systems, though in other settings it remains confined to pilots due to weak institutional capacity.

South Asia faces significant challenges: 40 percent of the respondents reported rare use, and only 15 percent consistent application. In-house capacity is very low, with 40 percent reporting no capacity at all—the highest globally—reflecting major institutional gaps.

Results from the Middle East and North Africa present mixed patterns, with NbS largely limited to pilots and urban greening projects—including mangrove restoration and constructed wetlands—which are often dropped at the design stage. Barriers include the lack of mandates and a persistent preference for conventional grey infrastructure.

Discussion

These findings show that NbS face systemic barriers that go beyond technical or financial constraints (World Bank, 2018). While awareness is growing, implementation remains limited due to deeper institutional and professional challenges. The higher adoption rates in some lower-income contexts appear driven by donor requirements rather than domestic capacity, which creates vulnerability when external support shifts, as maintenance arrangements remain underdeveloped across all country income levels.

NbS are largely concentrated in the water and urban sectors, with little presence in transport or energy infrastructure; this is due to sectoral siloes, which prevents cross-learning. Their persistent absence from codes, standards, and procurement processes—even in high-income countries with successful pilots—is a sign of regulatory lag and professional resistance. Weak maintenance arrangements and limited in-house capacity further indicate that NbS are often treated as environmental add-ons rather than integral infrastructure components (Martin et al., 2025).

The evidence underscores the need to embed NbS in engineering curricula, mandate their consideration in codes and standards, establish dedicated financing mechanisms, and build institutional capacity for long-term management.

8. Monitoring Systems

Global Target D of the Sendai Framework for Disaster Risk Reduction seeks to "substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030" (UNDRR, n.d.). It highlights the importance of strengthening resilience through risk-informed design, the duplication of key infrastructure components so that essential services can continue during disruptions, and continuity planning to ensure that essential systems can withstand shocks and recover quickly. Progress is monitored through indicators that track facility damage and service disruptions. Between 2015 and 2023, countries reported an annual average of 92,199 critical infrastructure units damaged or destroyed and over 1.6 million basic service facilities disrupted due to disasters (UNDRR, n.d.).

The GIRS for Experts and Professionals captured information (through online questionnaire response only) on the current use of monitoring systems for disaster-related infrastructure damage and the role of asset registries as supporting evidence for Target D implementation.

KEY FINDING 12

Infrastructure damage monitoring systems and asset registers show fundamental weaknesses globally, with only 16 percent of the respondents noting systematic monitoring use and 15 percent reporting the maintenance of comprehensive asset registries. Gaps span country income levels and regions, signifying that institutional and governance factors, and not resources alone, drive effectiveness. Reliance on reactive assessments and donor-driven initiatives limits evidence-based planning for long-term resilience.

8.1 Monitoring Systems for Disaster-related Infrastructure Damage

Monitoring systems for disaster-related infrastructure damage are structured mechanisms that combine data collection, reporting, and analysis to track the condition and performance of infrastructure assets during and after disasters. They provide governments and stakeholders with timely, accurate, and actionable information to support risk reduction, emergency response, recovery planning, and long-term resilience. Examples include government disaster loss databases, remote sensing and satellite-based assessments, mobile inspection apps for field engineers, and sector-specific systems for transport, energy, water, and other critical infrastructure.

Global trends

Respondents' views on monitoring systems for disaster-related infrastructure damage reveal that consistent, nationwide approaches are rare globally. Only 16 percent of the respondents reported systematic use of standardized national systems, while 30 percent noted that such systems exist but lack consistent application. The largest proportion (31 percent) highlighted the reliance on international methodologies such as post-disaster needs assessment (PDNA), but only for big disasters, indicating that monitoring is reactive rather than an integrated practice.[2]

Sectoral and stakeholder perspectives show minimal variation. Respondents from the buildings sector reported slightly weaker implementation of monitoring systems, with a quarter of them indicating that such systems exist but lack systematic application, compared with a third of respondents from other infrastructure sectors reporting the same. Government respondents acknowledged the gap, with one-third admitting that national systems exist but are used inconsistently. This consensus across sectors and stakeholders confirms that monitoring challenges are systemic rather than isolated and limited to particular domains. Similar patterns are reflected across all country vulnerability contexts.

Country income level analysis

Results for monitoring systems display unexpected patterns across country income levels, with no clear correlation between wealth and systematic implementation (Figure 57). Respondents from high-income countries perceived surprising weaknesses: 32 percent reported that infrastructure damage is rarely measured despite the availability of resources; only 18 percent noted systematic use, and 31 percent stated that systems exist but are underutilized, highlighting gaps in implementation rather than resource constraints.

Responses from lower-middle-income countries point to the weakest application, with just 11 percent indicating systematic use; around a third of the respondents perceived reliance on international methodologies, and another third noted that damage is rarely measured—signifying heavy dependence on external assessments rather than domestic capacity.

In low-income countries, the proportion of respondents reporting systematic application was the highest at 23 percent, though this likely reflects targeted donor-supported initiatives rather than comprehensive national frameworks. However, 27 percent still reported infrequent measurement, indicating pockets of externally driven capability rather than systematic coverage.

[2] A PDNA is a government-led, integrated, multi-sectoral evaluation conducted in the aftermath of a disaster (United Nations Development Group et al., 2013). It assesses both physical damages and economic losses (e.g., infrastructure, productive assets), as well as the recovery needs of the affected populations. The goal is to develop a coordinated recovery framework to guide early and long-term recovery planning and mobilize resources effectively.

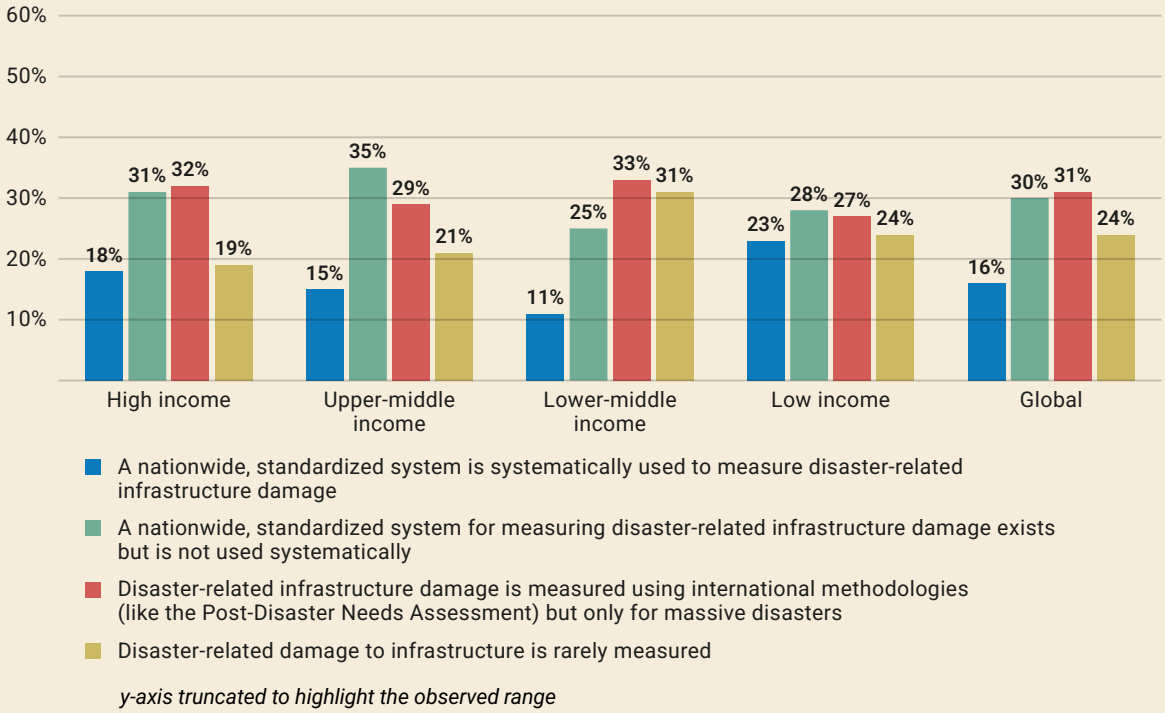


Figure 57

Monitoring systems used to measure disaster-related damage, by country income level

Source: Authors' analysis

Responses from upper-middle-income countries mirrored the high-income patterns: 35 percent reported underused systems, while only 15 percent noted systematic application—suggesting that institutional rather than financial barriers are the main constraint.

Regional analysis

Regional patterns (**Figure 58**) indicate that institutional traditions and disaster exposure influence monitoring capacity more than just resource availability. The East Asia and Pacific region leads, with 34 percent of the respondents reporting systematic use, which likely reflects the well-established disaster management practices in hazard-prone contexts. Nevertheless, 28 percent noted that though systems exist, they are underutilized, indicating that even the strongest region faces implementation challenges.

Results from Latin America and the Caribbean and from Europe and Central Asia display similar trends: Around 31–35 percent of the respondents reported underused systems, but only 10 percent perceived systematic application, suggesting that frameworks exist but lack the institutional mechanisms necessary for consistent implementation. Respondents from North America (37 percent) mentioned the heavy reliance on international methodologies despite the region's high-income status, reflecting a preference for using established external frameworks over developing national systems.

Results from South Asia and Sub-Saharan Africa reveal the weakest monitoring capacity, with just 10–15 percent of the respondents reporting systematic use and around 30 percent stating that damage is rarely measured, creating critical gaps in understanding infrastructure vulnerability. Respondents from the Middle East and North Africa presented a more balanced picture, with 25 percent reporting systematic use, indicating emerging capacity in a region with growing hazard awareness.

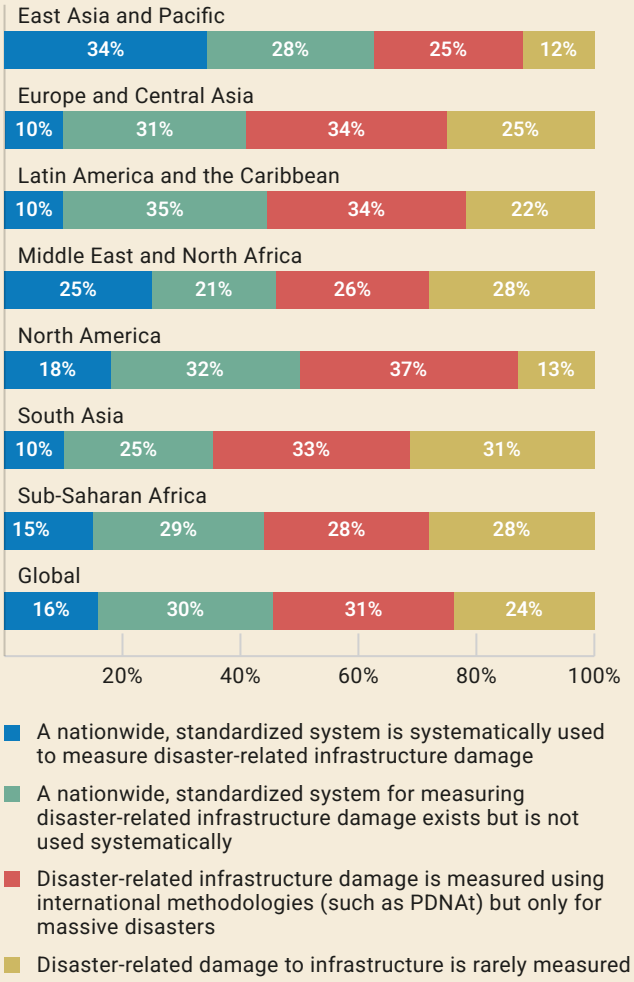


Figure 58

Monitoring systems used to measure disaster-related damage, by GIR 2023 region

Source: Authors' analysis

8.2 Infrastructure Asset Registers

Global trends

Responses related to infrastructure asset registers show even greater gaps than those on monitoring systems, with only 15 percent of the respondents noting systematic use of nationwide, standardized, and up-to-date registries. The most commonly reported situation (35 percent of the responses) involves registries that exist but are incomplete or inconsistently updated, while 32 percent of the respondents stated that there is no formal registry and only partial databases are available.

Sectoral perspectives reveal that infrastructure asset registers in the building sector are slightly less developed than those in other infrastructure sectors. However, both the building sector and other infrastructure sectors are far from achieving systematic integration with resilience planning.

Country income level analysis

When examined by income group (**Figure 59**), responses on asset registers present some counterintuitive findings.

In high-income countries, 14 percent of the respondents stated that there are no standardized infrastructure asset

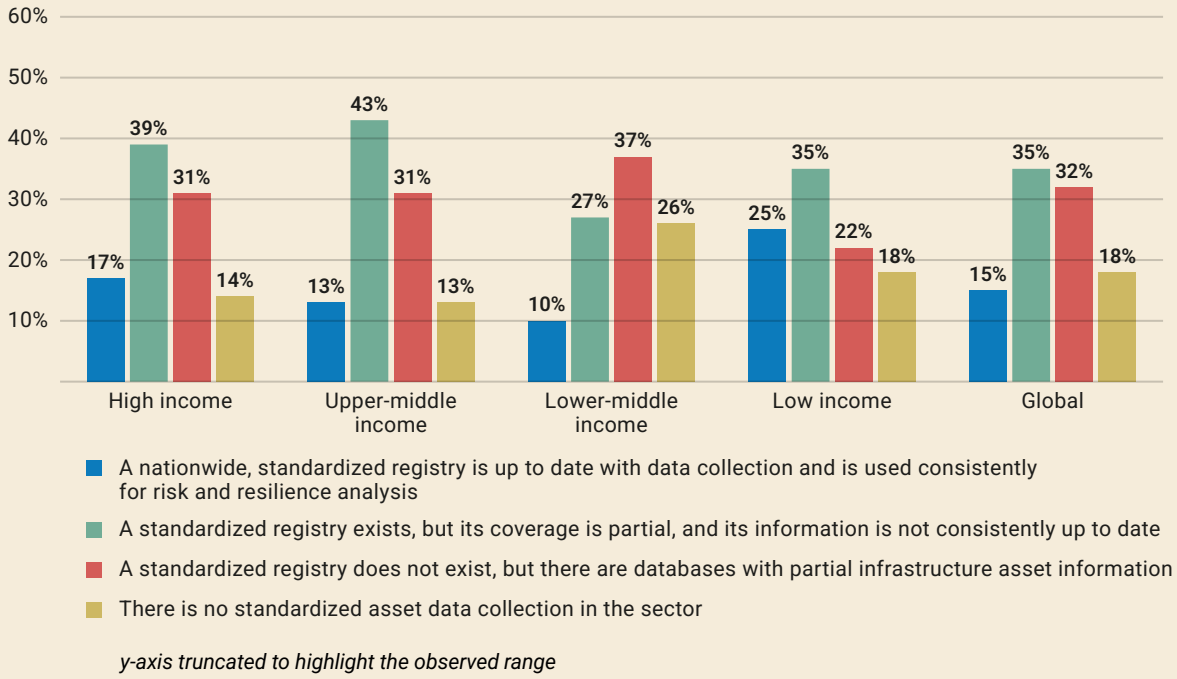


Figure 59

Infrastructure asset registers, by country income level

Source: Authors' analysis

registries, while 17 percent reported comprehensive, consistently used registries.

Results from lower-middle-income countries exhibit the biggest gaps, as 26 percent of the respondents noted that there is no standardized asset data collection at all, and only 10 percent answered that nationwide registries exist and are up to date with data collection.

Results from low-income countries show diversity among these countries: 25 percent of the respondents—the highest share among all the groups—noted that nationwide, standardized registries exist and are used consistently for risk and resilience analysis, yet 18 percent responded that there is no standardized asset data collection at all.

Regional patterns (**Figure 60**) in responses on asset registers reveal significant disparities in data infrastructure development. The East Asia and Pacific region leads, with 32 percent of the respondents reporting comprehensive registries. However, an equal proportion regard their systems as incomplete, indicating that even regions with relatively strong national capacity face data quality challenges. Results from Latin America and the Caribbean show the weakest performance, with only 6 percent of the respondents reporting comprehensive registries and 40 percent noting that existing registers are incomplete or outdated, a gap that severely undermines evidence-based resilience planning.

Responses from Europe and Central Asia demonstrate similar weaknesses, with just 13 percent of the respondents reporting comprehensive systems and 41 percent mentioning incomplete or outdated registries, which is surprising given the region's institutional capacity. Results from the Middle East and North Africa show relatively good performance, with 30 percent of the respondents noting comprehensive coverage, though 32 percent reported incomplete systems, reflecting emerging but uneven data infrastructure.

Responses from North America show unexpected weaknesses, with only 6 percent of the respondents describing comprehensive registries, highlighting that even wealthy regions struggle with systematic asset data management. Results from South Asia reveal severe constraints, with only 8 percent of the respondents reporting comprehensive coverage and 34 percent noting the absence of standardized systems, which creates fundamental barriers to risk-informed infrastructure planning. Responses from Sub-Saharan

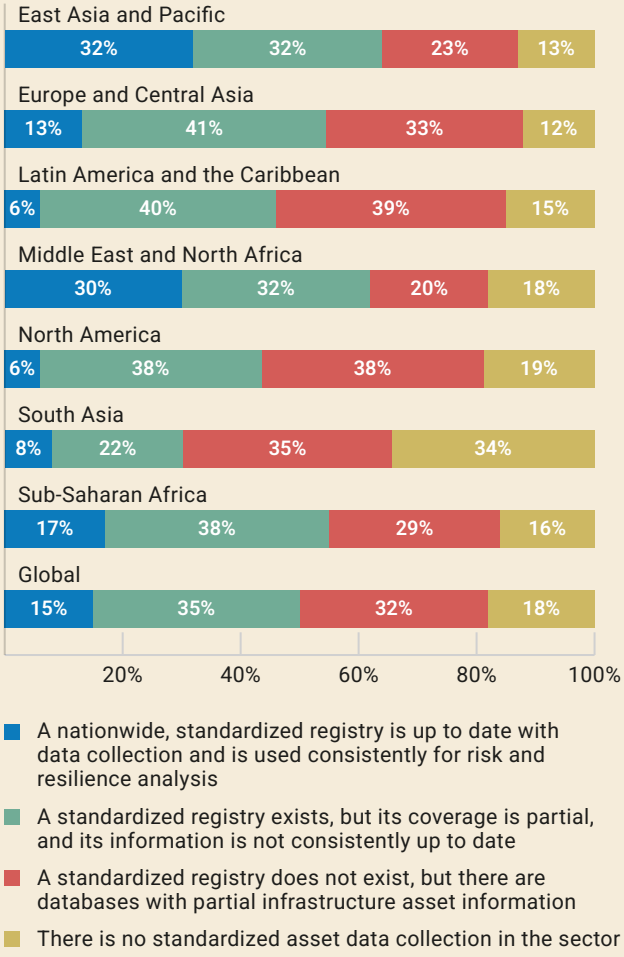


Figure 60

Infrastructure asset registers, by GIR 2023 region

Source: Authors' analysis

Africa show moderate performance, with 17 percent of the respondents noting comprehensive registries and 38 percent reporting incomplete systems, suggesting gradual progress from a low baseline.

Discussion

These findings expose fundamental weaknesses in the information systems that underpin infrastructure resilience globally. The disconnect between country income levels and system effectiveness indicates that institutional and governance factors often outweigh mere resource availability. The consistently stronger performance of the East Asia and Pacific region in both monitoring systems and asset registers likely reflects lessons learned from repeated disaster exposure rather than inherent technical capacity. However, caution should be exercised regarding the robustness of these findings due to the potential for optimism bias in this region. In contrast, the weaker performance of some high-income regions suggests that limited disaster experience can foster complacency in system development.

Reliance on international methodologies for damage assessment, particularly in middle-income countries, signifies a tension between national sovereignty aspirations and practical capacity. While external frameworks offer standardization, they may fail to capture local contexts or build domestic expertise. Similarly, the unexpected strength of monitoring systems in certain low-income countries likely reflects concentrated donor investment, raising concerns about sustainability and genuine national ownership.

To ensure effective, evidence-based infrastructure resilience planning, systematic investment in both monitoring systems and asset registers is essential. Without this, planning will continue to rely on incomplete, inconsistent, or externally driven data, undermining risk reduction strategies.

9. Governments' Top Priorities for Infrastructure Resilience

KEY FINDING 13

Globally, strengthening regulatory frameworks emerges as the top government priority for infrastructure resilience, as cited by around half the respondents. Disaster preparedness, proactive maintenance, and financing follow, while cross-sectoral coordination received surprisingly low priority (22 percent of the respondents) despite experts' recognition of its importance. Lower-income countries were expected to focus on establishing basic regulatory frameworks (56 percent), middle-income countries to emphasize enforcement and transparency, and high-income countries to prioritize modernizing standards and integrating climate considerations (46 percent). Further, regional patterns reflect hazard and governance contexts, highlighting the need for tailored, complementary measures alongside regulatory reform to strengthen resilience.

Global trends

Results reveal a clear hierarchy of government priorities for strengthening infrastructure resilience (**Figure 61**). Policies, standards, codes, and regulations emerge as the dominant concern, with half the respondents identifying them as essential. Disaster preparedness and response planning alongside proactive maintenance and repairs follow at 34 percent of the responses, reflecting the recognition that long-term planning and routine upkeep are equally vital. Financing (28 percent) and institutional stability and technical capacity (26 percent) were also widely seen as critical, while cross-sectoral coordination mechanisms and transparency, accountability, and enforcement of the rule of law received less emphasis at 22 percent each. Public education ranks the lowest at 16 percent, suggesting that respondents viewed it as secondary to institutional and regulatory priorities.

x-axis truncated to highlight the observed range

Figure 61

Respondents' views of the top priorities for governments

Source: Authors' analysis

Country income level analysis

Across income groups, strengthening regulatory frameworks emerges as the top priority. However, the weight given to it and the complementary priorities vary significantly with economic development (**Figure 62**).

Lower-middle-income and low-income country respondents had the strongest consensus on regulatory reform at 56 and 50 percent, respectively. Expert interviews indicate that this reveals fundamental gaps in basic frameworks, with governments needing to mainstream resilience into procurement and mandate climate-proofing of assets. The interviewed experts from these countries emphasized embedding resilience in codes for critical assets while simultaneously building cross-sectoral coordination and addressing chronic under-investment in maintenance. The challenge of strengthening enforcement and inter-ministerial coordination while establishing basic regulatory frameworks illustrates the compound difficulties facing lower-income contexts.

Questionnaire responses from high-income and upper-middle-income countries also prioritized regulatory frameworks at around 46–47 percent, but expert interviews reveal distinctly different focuses. The interviewed experts from high-income countries stressed that existing frameworks should be updated so that they are climate-informed and systematically applied across sectors. In addition, they recommended embedding climate projections in design standards, strengthening land-use rules, and closing enforcement gaps. The emphasis in these contexts shifts from creating frameworks to modernizing them, as the interviewed experts highlighted the existence of fragmented and outdated codes that need to be aligned between national and sub-national frameworks.

Proactive maintenance and repairs rank particularly high among high- and upper-middle-income groups at 35–36 percent of the responses, reflecting concerns about ageing infrastructure. Expert inputs confirm this priority, with emphasis on proactive inspections and retrofits for ageing assets, and maintenance of critical infrastructure in contexts with deteriorating systems.

The governance dimension has revealing patterns in the data. Lower-middle-income country respondents showed the highest concern for institutional stability and technical capacity at 31 percent, while transparency and accountability received stronger emphasis in lower- and low-income contexts. Expert interviews provide additional context: Corruption, weak enforcement, poor budget execution, and the politicizing of infrastructure resilience emerge as critical barriers. The interviewed experts from upper-middle-income countries particularly stressed tackling governance and accountability gaps along with policy strengthening, as weak accountability can undermine even well-designed frameworks.

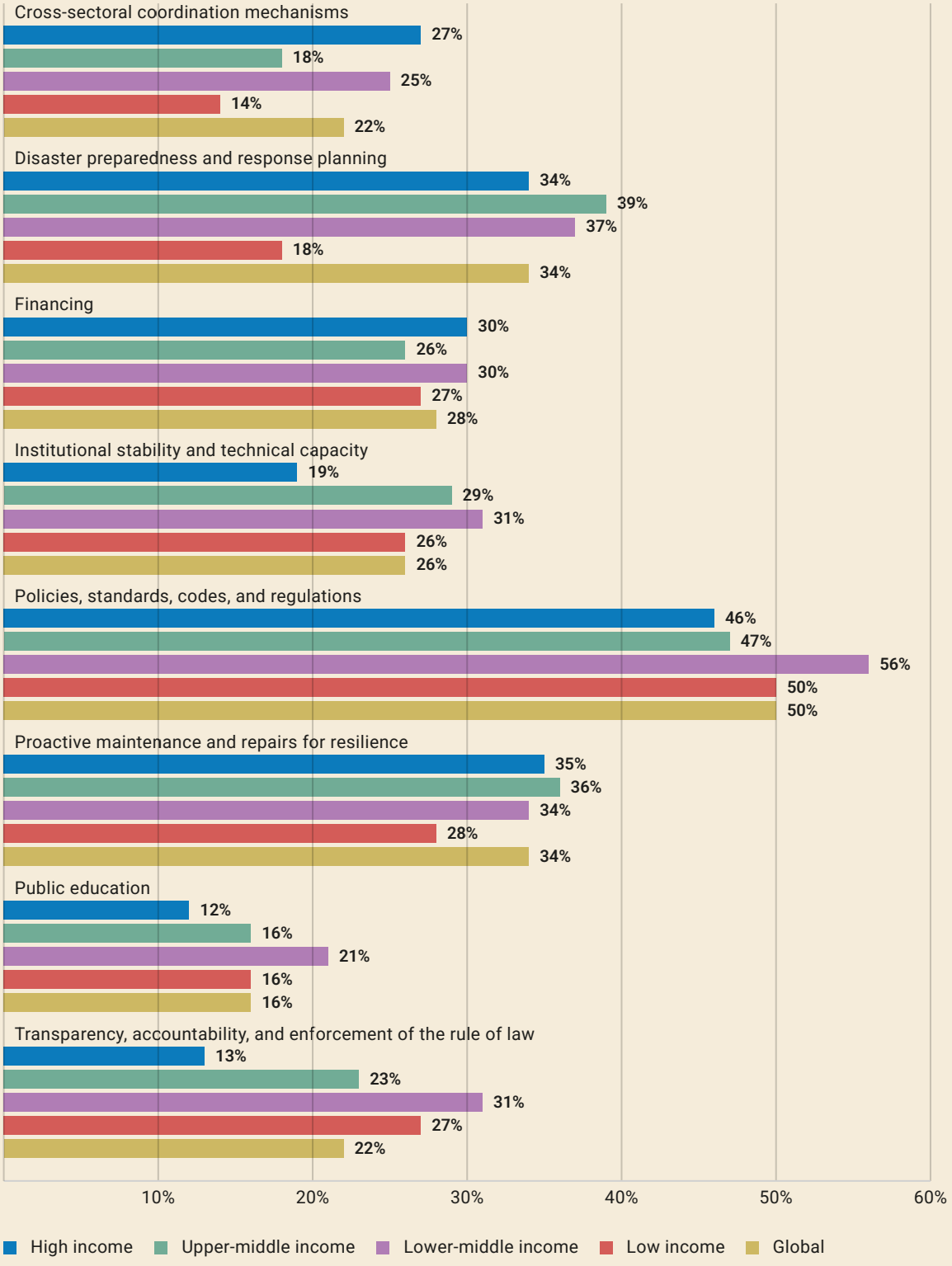


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Figure 62

Respondents' views of the top priorities for governments, by income group

Source: Authors' analysis

Regional analysis

Regional priorities reveal how geographical, institutional, and hazard contexts go beyond income levels in shaping resilience agendas (Figure 63).

South Asian respondents demonstrated the most comprehensive approach, with the highest emphasis on regulatory reform at 60 percent of the responses, combined with a strong focus on transparency and accountability (31

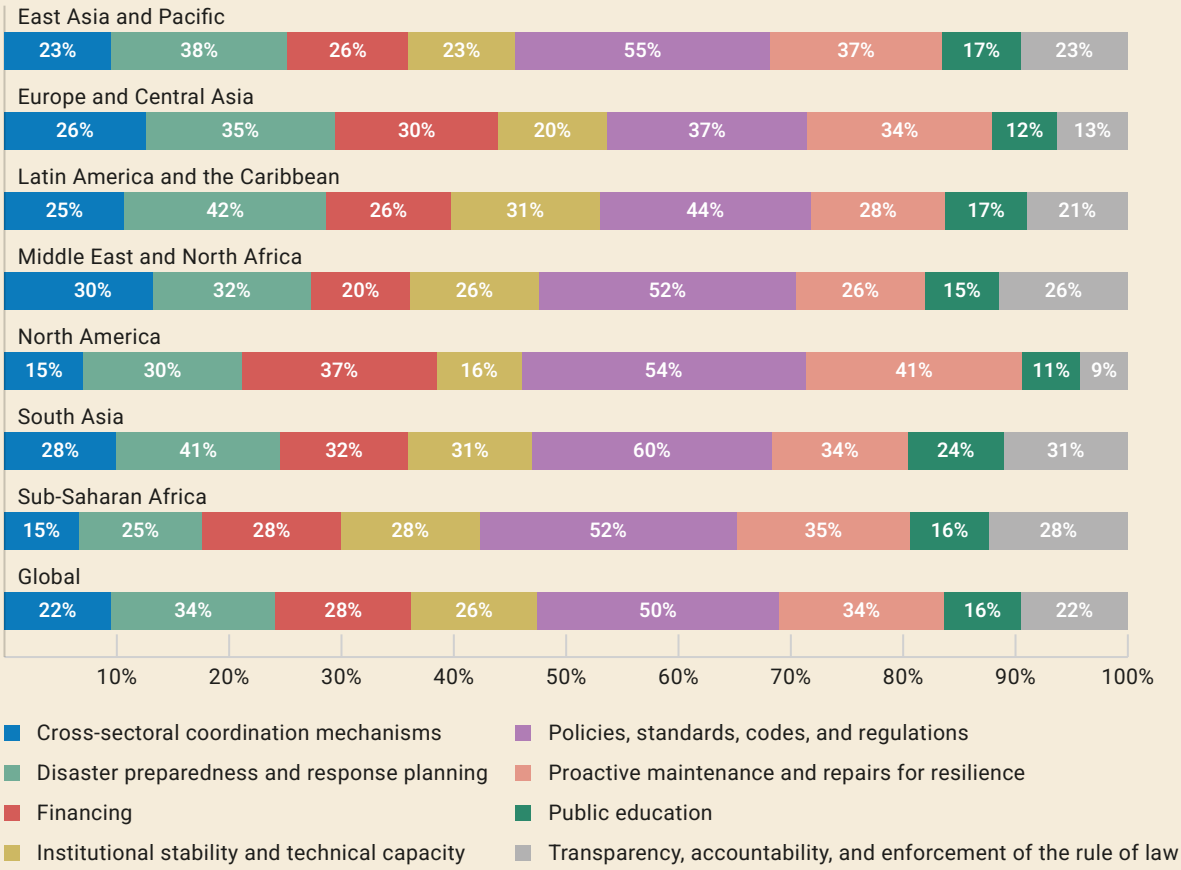


Figure 63

Respondents' views of the top priorities for governments, by GIR 2023 region

Source: Authors' analysis

percent), disaster preparedness (41 percent), and institutional capacity (31 percent). This multi-pronged priority setting reflects systemic challenges that require simultaneous action across governance, technical, and operational dimensions.

Responses from Latin America and the Caribbean present a distinct pattern, with the highest regional priority being disaster preparedness at 42 percent. Expert input reveals why this supersedes other concerns: the urgent necessity to embed risk considerations into regulations while overcoming corruption and weak enforcement. The interviewed experts stressed the vital importance of law enforcement and transparency—as corruption undermines resilience—and the need to depoliticize projects. The emphasis on updating codes while addressing weak accountability illustrates how governance failures compound technical gaps.

Responses from North America show the unique prioritization of both proactive maintenance at 41 percent and financing at 37 percent, the highest across all regions. Expert interviews confirm that modernizing standards by including climate data and enforcing compliance is a paramount necessity and that fragmented and outdated codes require urgent attention. The combination of ageing infrastructure and outdated regulatory frameworks creates a dual challenge distinct from the concerns in other regions.

Survey findings from Sub-Saharan Africa balance regulatory priorities at 52 percent of the responses, with a relatively higher emphasis on transparency and accountability at 28 percent. Expert interviews emphasize institutional strengthening along with improving codes and technical capacity, highlighting the importance of building enforcement capability and investing in skills. The need

for training civil servants while embedding resilience in codes illustrates the human resource dimension of regulatory reform.

Responses from Europe and Central Asia give consistent emphasis to multiple priorities without extreme values. Expert input identifies updating codes and standards, strengthening institutions, and investing in proactive maintenance and coordination as interconnected priorities. The emphasis on institutional coordination and nationwide enforcement reflects the existence of relatively mature systems requiring integration rather than fundamental reform.

Questionnaire results from the East Asia and Pacific region prioritize regulatory reform at 55 percent of the responses and disaster preparedness at 38 percent. Expert insights reveal a focus on coordination and embedding climate risk in codes, with experts from high-income contexts emphasizing cross-sectoral mechanisms operating through new disaster management agencies and departmental collaboration. Embedding climate risk in codes while prioritizing co-benefits is a sophisticated approach to regulatory reform.

Respondents from the Middle East and North Africa region expressed balanced priorities across regulations, preparedness, and financing. Experts emphasized rehabilitating existing assets; strengthening water and energy management; disaster preparedness, particularly flood preparedness; and integrating resilience into planning regulations as the main priorities, illustrating the emerging hazard awareness in traditionally lower-risk contexts.

Discussion

These findings reveal that while regulatory reform is the universal top priority, its specific nature varies fundamentally across contexts. Lower-income countries require basic framework establishment, middle-income countries need improvements in enforcement and transparency, and high-income countries need to focus on climate integration and modernization of existing standards.

The relatively low prioritization of cross-sectoral coordination at 22 percent of the responses across all groups contrasts with experts' emphasis on overcoming siloes and managing systemic risks. This suggests either that coordination is seen as embedded within other priorities rather than a standalone or that its importance is recognized but it is not prioritized given more pressing needs.

The emphasis on maintenance in higher-income contexts versus governance and transparency in lower-income settings reflects the different stages of infrastructure life cycle management. While wealthy nations grapple with ageing assets requiring proactive maintenance, developing countries face more fundamental challenges as weak governance undermines any resilience efforts.

The consistent undervaluing of public education at just 16 percent of the responses globally suggests a technocratic approach to resilience that may overlook community engagement. This gap between the technical and social aspects of resilience could limit the effectiveness of even well-designed regulatory and institutional reforms.

These patterns indicate that effective resilience strategies must be tailored not just to country income levels but to specific governance, institutional, and hazard contexts, with regulatory reform serving as the foundation but requiring different complementary measures across different settings.

10. Small Island Developing States

SIDS face distinctive challenges in building resilient infrastructure due to their geographical isolation, limited resources, small economies of scale, and high exposure to climate change and natural hazards. While presenting the results for all participating SIDS, this section provides a deep dive into the findings for Pacific SIDS and Caribbean SIDS, which contributed the largest share of questionnaire responses and expert interviews. Only selected charts have been included in what follows.

10.1 Institutions and Governance

10.1.1 Public Sector's Capacity

Only 14 percent of the respondents across all SIDS rated the public sector's institutional capacity for implementing infrastructure resilience as 'adequate'; this dropped to 3 percent in the Pacific and 6 percent in the Caribbean (Figure 64). Human resources availability was rated as 'limited' by 43 percent overall and by 61 percent in the Pacific.

The interviewed experts from both regions agreed that severe human resource limitations represent the fundamental constraint undermining even well-designed frameworks. Both Pacific and Caribbean SIDS struggle with implementation weakened by fragmented governance, frequent restructuring, and dependence on donor-driven projects. The absence of coordinating structures, frequent changes in scope, and reliance on political will rather than institutional systems undermine continuity. Human resources availability is uneven, with shortages of technical staff, auditors, and inspectors. Existing personnel are often under-trained or not aligned with resilience objectives (Wilkinson et al., 2025).

10.1.2 Private Sector's Capacity

Across all SIDS (**Figure 65**), 24 percent of the respondents assessed the private sector's technical capacity as 'adequate', while only 14 percent considered human resources availability adequate. The majority rated both as 'variable', with a slightly higher share of ratings in the Caribbean (48 percent for human resources and 47 percent for technical capacity) compared with the Pacific (39 percent and 46 percent, respectively).

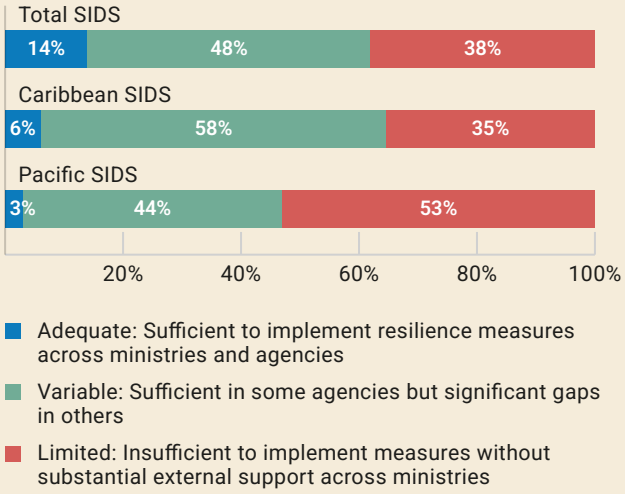


Figure 64

Public sector's technical capacity and expertise for infrastructure resilience implementation, SIDS

Source: Authors' analysis

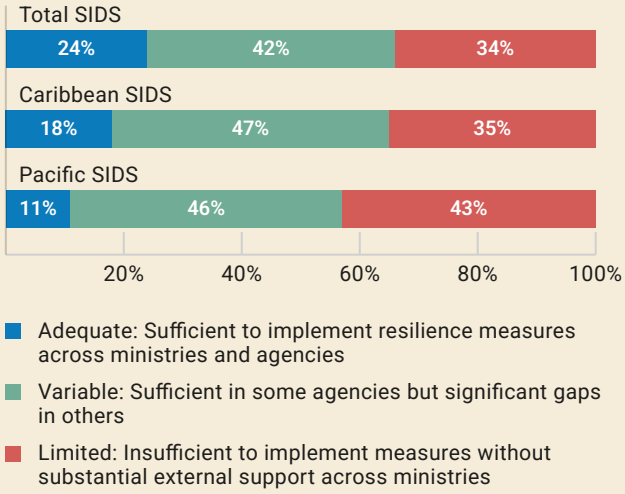


Figure 65

Private sector's technical capacity and expertise for infrastructure resilience implementation (SIDS)

Source: Authors' analysis

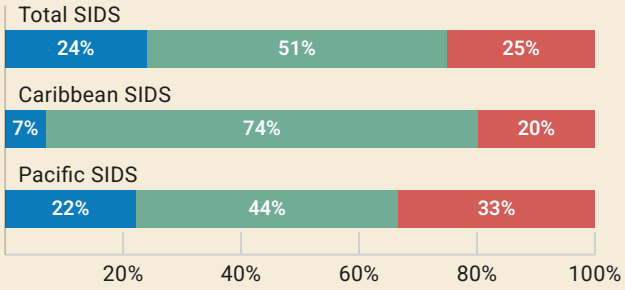
Expert interviews reveal that the private sector's technical capacity shows disparities across SIDS, largely determined by market size and economic development levels. Both regions face structural constraints from brain drain and dependence on foreign contractors, which creates systematic gaps in local expertise. In the Pacific, qualified engineers are particularly scarce (Gibson & McKenzie, 2012); there may be only a handful of licensed engineers in an entire ministry, and those who do qualify often migrate overseas, leaving countries with insufficient numbers of licensed engineers. Even where competent local firms exist, they are often excluded from donor-funded training opportunities.

The Caribbean demonstrates more variable private-sector engagement, with some contexts showing technically competent firms leading infrastructure projects. However, capacity remains uneven, and technical expertise is frequently imported, especially in construction and tourism, leaving long-term local capacity underdeveloped with little knowledge transfer from international experts.

10.1.3 Retrofitting Programmes

Systematic retrofitting programmes are uncommon across SIDS: 41 percent of the respondents noted only sporadic projects, and 26 percent reported such projects as rare or non-existent. This is more pronounced in the Caribbean, where only 4 percent reported nationwide programmes (compared with 11 percent in the Pacific), while 56 percent noted sporadic efforts only.

The interviewed experts confirmed that systematic retrofitting programmes are virtually absent in both regions, and actions are ad hoc or reactive rather than preventive. Retrofitting is typically limited to post-disaster reconstruction, such as repairs to markets or evacuation centres following cyclones. Small-scale retrofits occur informally or as part of modifications to existing assets but without formal programme structures. While some residential or coastal retrofits are being scoped or implemented, these lack clear national frameworks and standards, and interventions remain disaster-driven. A key difference emerges in reconstruction approaches: Caribbean SIDS often prefer replacing assets to

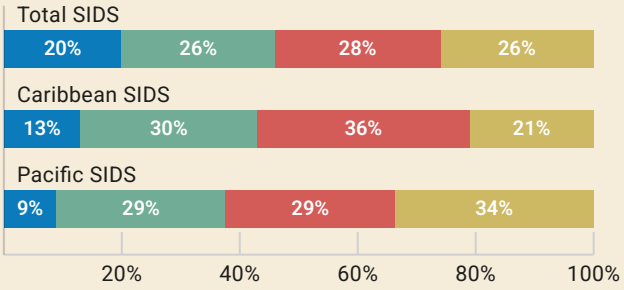


- Consistently strong: Formal coordination mechanisms exist and function effectively
- Variable: Existing mechanisms are sporadic or are only activated for major disasters
- Consistently weak: Few or no formal coordination mechanisms exist between agencies

Figure 66

Existing regulations, codes, and standards for infrastructure resilience (SIDS)

Source: Authors' analysis



- Enforcement includes mandatory third-party verification/ certification and meaningful penalties for non-compliance for all projects
- Enforcement mechanisms exist, but are inspections are limited to national-level, large-scale projects
- Enforcement mechanisms exist but with limited inspection capacity
- Minimal formal enforcement mechanisms or resources allocated

Figure 67

Enforcement of regulations, codes, and standards for infrastructure resilience (SIDS)

Source: Authors' analysis

retrofitting them, which can undermine long-term resilience.

10.1.4 Inter-agency Coordination Capacity

Coordination between DRM agencies and infrastructure organizations is more effective during response and recovery than in hazard mitigation and disaster preparation. Across all SIDS, 77 percent of the respondents rated disaster response and recovery as 'adequate' or 'variable', compared with 69 percent for hazard mitigation and 70 percent for disaster preparedness.

Pacific respondents considered coordination weaker overall, with over 45 percent rating hazard mitigation and disaster preparedness as weak and around one-third rating disaster response and recovery as weak. Caribbean figures are better: 27 percent considered hazard mitigation weak, and 22 percent perceived preparedness, response, and recovery to be weak.

Expert interviews reveal common patterns across both regions. Disaster preparation and response function relatively effectively through national committees, cross-ministry groups, or cluster systems, bringing together government, private-sector actors, and communities, and are often supported by national emergency operation centres. Response typically enables quick mobilization across sectors. However, recovery remains the weakest stage in both regions, with frameworks existing but implementation often fragmented, slow, or overly dependent on external players. In the Pacific, recovery activities are particularly limited on the outer islands, and assets are sometimes left unrepaired. In the Caribbean, political transitions, resource gaps, and weak follow-through undermine long-term collaboration, and projects are frequently abandoned after transitions.

10.1.5 Regulations, Codes, and Standards

The majority of respondents (51 percent) agreed that regulations, codes, and standards exist but do not adequately address infrastructure resilience, fail to reflect the full hazard landscape, or have

not been updated for a long time. Only 7 percent of the Caribbean respondents considered them to be consistently strong, compared with 22 percent in the Pacific (**Figure 66**). Respondents were almost evenly split between strong and weak enforcement (**Figure 67**). The largest share of the Caribbean respondents (36 percent) reported limited inspection capacity, while the largest share of the Pacific respondents (34 percent) noted only minimal formal enforcement mechanisms.

The interviewed experts confirmed that regulations, codes, and standards exist in both regions but there are fundamental adequacy and enforcement gaps. Common issues include codes copied from foreign standards that might not be entirely suited to the local context, missing earthquake provisions, and unclear enforcement mechanisms. Compliance is largely voluntary, without donor or insurance requirements. Building codes may be updated after major disasters, but sectoral standards remain limited. Multiple technical codes exist, but they are inconsistently updated, and enforcement is poor. While regional standards—such as the Caribbean Uniform Building Code (Caribbean Development Bank, n.d.)—exist, the real weakness lies in inconsistent enforcement and lack of political will. Standards under revision often lack legal enforceability, resulting in partial compliance by formal firms, while most construction activities are informal and unregulated.

Box 9

Case study: Harmonizing building codes in the Pacific

In 2021, the Pacific Regional Infrastructure Facility (PRIF, n.d.) launched a technical assistance initiative titled Improving National Building Codes and Standards in the Pacific, which established an online repository of building codes, guidelines, and reference documents for the Pacific Island nations. This repository aggregates region-wide and country-specific codes to support coordination, harmonization, and capacity development across the region. By providing unified access to legal texts, commentaries, and best-practice guidelines, PRIF aims to facilitate peer learning, promote consistent resilience standards, and strengthen regulatory frameworks in climate-vulnerable Pacific states.

10.2 Finance

10.2.1 Adequacy of Government Funding

Government funding was considered inadequate for new infrastructure implementation by 51 percent of the respondents (**Figure 68**), risk-based asset maintenance and repair by 66 percent, and retrofitting by 58 percent. The gap is particularly severe: 0 percent of the Pacific respondents reported that funding covered more than 75 percent of identified resilience needs, compared with 3–5 percent in the Caribbean.

Expert interviews confirm that government funding is systematically inadequate in both regions, with heavy reliance on donors and international financial institutions. Domestic resources typically cover only a fraction of project costs—such as land acquisition or safeguards—while capital funding comes from development partners. Most SIDS cannot fund maintenance or retrofitting from domestic budgets and depend almost entirely on aid flows. Ministries compile needs lists for donors, and projects can proceed only if external partners agree to fund them. Budget-tracking gaps make it difficult to measure adequacy: Resilience expenditures are not systematically tagged, and the distinction between donor and domestic funds is blurred.

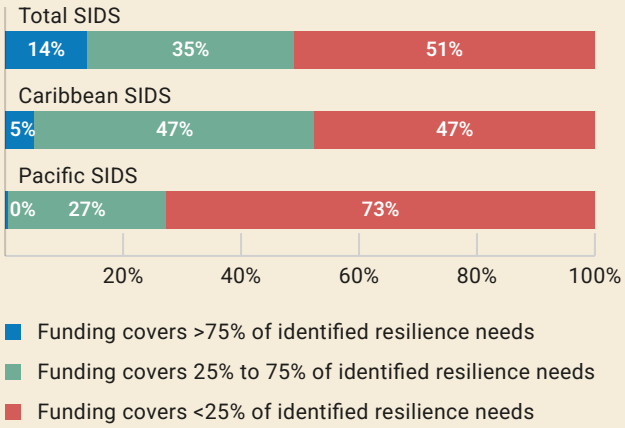


Figure 68

Adequacy of government funding for implementing resilience in new infrastructure (SIDS)

Source: Authors' analysis

10.2.2 Financial Mechanisms

Alternative financial mechanisms are rarely used: 53 percent of the respondents reported that PPP contracts are rarely or not at all used; 72 percent noted the same for thematic bonds and 66 percent for insurance. Pacific SIDS present a slightly more negative picture (68, 84, and 71 percent, respectively) compared with the Caribbean (51, 71, and 70 percent, respectively).

Expert interviews confirm limited uptake in both regions, mostly driven by donors rather than domestic systems. Insurance penetration is very low, PPPs are not leveraged for resilience, and thematic bonds are largely absent. In Pacific SIDS, there are sector-specific applications—such as independent power producers and power purchase agreements (PPAs)—to finance renewable energy infrastructure. A PPA provides long-term revenue certainty, reducing market risks and making projects more bankable. It is an instrument that is particularly useful in SIDS, where local utilities often have limited capacity to absorb financial and operational risks (PRIF, 2020). Experts highlighted that in the Caribbean, small-scale funds provide grants or subsidies for resilience upgrades, but these are narrow in scope and under-resourced (Wilkinson et al., 2023).

10.3 Risk Assessments

10.3.1 Current Risk Assessment Practice

Across SIDS, 68 percent of the respondents noted that hazard and risk assessments are mandated in codes and standards and are consistently or sometimes used. The share of respondents from the Caribbean who reported this was higher (81 percent) than in the Pacific (51 percent).

The interviewed experts drew a different picture, however: Hazard and risk assessments show uneven application in both regions and are typically driven by donor requirements rather than systematic national frameworks. Some contexts require assessments for all new projects to secure financing; assessments are embedded in feasibility and design. However, proactive assessments are scarce, with hazard references used selectively and retrofits mainly following disasters. Integration outside major donor programmes remains limited, as risk modelling is rarely explicitly mandated in codes.

10.3.2 Future Climate Scenarios

Across all SIDS, 55 percent of the respondents noted that future climate considerations are mandated and are consistently or sometimes used; this number rises to 66 percent in the Caribbean but falls to 42 percent in the Pacific region.

According to the interviewed experts, however, integration of future climate scenarios is limited in both regions. In most contexts, either standard scenarios are lacking—and there are ongoing debates over which to use—or reference foreign standards are not adapted to local hazards. Assessments and designs rely mainly on historical hazard data.

Caribbean and Pacific SIDS show limited integration of future climate scenarios, according to expert input. Climate projections may be referenced in specific donor-supported projects, particularly for water and drought management, but this is the exception rather than the rule.

Box 10

Case study: Tonga's multi-hazard risk assessment

Commissioned in 2020 and launched at the United Nations Climate Change Conference in 2021, the Asian Development Bank (ADB)–Tonga's multi-hazard climate and disaster risk assessment examined more than 28,000 buildings, 1,200 km of roads, 26,000 power assets, and 500 water assets (ADB, 2021). It assessed risks from earthquakes, cyclones, tsunamis, inland flooding, and coastal inundation, while also factoring in climate change impacts such as sea-level rise. The results were formally adopted by Tonga's cabinet in August 2021, providing a foundation for national decisions on where to locate future infrastructure and how to strengthen long-term resilience planning.

10.3.3 Data Availability

Across all SIDS, 50 percent of the respondents reported that up-to-date data for hazard, vulnerability, and risk assessments are available; this number rises to 58 percent in the Caribbean but falls to only 27 percent in the Pacific region.

The interviewed experts offered a more cautious view, noting that although data exists in both regions, it faces severe challenges of accessibility, quality, and coverage. Common issues include outdated hazard maps, inconsistent donor methodologies, lack of asset inventories, and weak exposure data. Datasets are fragmented, undermined by weak interoperability, and defective or without monitoring equipment. Systemic barriers include siloed agencies, duplication of risk assessments, raw data not processed into usable formats, and access controls on government-held datasets. In the Caribbean specifically, experts pointed to high costs, limited localization, and cultural tendencies to dismiss imperfect data as unavailable, which further constrains accessibility.

10.3.4 Advanced Technologies

The majority of respondents (81 percent) noted that advanced technologies are used selectively in high-profile projects or are seldom used; this number increases to 94 percent in the Caribbean and 84 percent in the Pacific region.

Both regions apply GIS, satellite imagery, and early-warning tools, usually in donor-led projects. Higher-capacity settings show more systematic integration, including the use of BIM, IoT, AI, and predictive maintenance platforms. However, adoption faces common barriers including outdated data, high costs, weak technical capacity, institutional silos, and financial

constraints. Caribbean SIDS are increasingly applying monitoring and inspection tools, including telemetric stations, sensors, drones, and LiDAR mapping, though often at basic levels. In both regions, capacity gaps restrict the ability to evaluate new technologies, weak maintenance and vandalism undermine systems, and reliance on donor-funded pilots prevents sustainable adoption. Governments cannot afford maintenance or updates when new technologies are introduced.

10.3.5 Nature-based Solutions

NbS appear in small-scale or pilot projects, but there is no systematic mainstreaming: 45 percent of the respondents noted that they are used in only a few projects, while 30 percent reported rare use. These numbers are similar across regions, with 79 percent of the Caribbean respondents and 82 percent of the Pacific respondents indicating sporadic use.

Both regions use NbS occasionally for coastal protection, slope stabilization, or catchment management—often linked to donor or NGO initiatives. Some Caribbean SIDS have hybrid systems combining ecological and engineered approaches. However, formal inclusion in codes remains absent in both regions, except in isolated high-capacity contexts. Expert interviews reveal that in-house capacity is highly uneven, with some ministries promoting NbS but without consistent government uptake, while others lack technical expertise and rely on external studies. Institutional capacity within government agencies is inadequate across both regions, with leadership coming from NGOs or civil society rather than infrastructure ministries.

Box 11

Case study: NbS inventory for Fiji

In Fiji, NbS are being implemented to enhance resilience against climate change impacts. The Nature-Based Solutions Inventory for Fiji, developed by the International Institute for Sustainable Development under the Climate Adaptation and Protected Areas initiative, showcases a variety of NbS projects across the country's ecosystems (International Institute for Sustainable Development et al., 2024). These projects are for the restoration of mangrove forests, construction of nature-based sea walls using materials such as vetiver grass and boulders, and rehabilitation of riverbanks with native vegetation, among others. Such initiatives aim to protect coastal communities from sea-level rise and extreme-weather events, while also preserving biodiversity and promoting sustainable livelihoods. The inventory serves as a valuable resource for stakeholders to understand the landscape of NbS implementation in Fiji and to facilitate further adoption and mainstreaming of these solutions.

Box 12

Case study:
Leveraging NbS for climate resilience in Saint Lucia

The Government of Saint Lucia (2020) has demonstrated strong institutional commitment to integrating NbS with national climate adaptation strategies. Central to this effort is the Department of Sustainable Development, which leads the implementation of the Resilient Ecosystems Adaptation Strategy and Action Plan 2020–2028. This plan emphasizes strengthening national policy and institutional, legal, and regulatory frameworks to improve natural resource management for securing ecological resilience and ecosystem-based adaptation to climate change.

Further, the government has partnered with international organizations to enhance NbS implementation. For instance, the Caribbean Natural Resources Institute (2025) launched a project aimed at removing technical, financial, and policy bottlenecks to nature-positive development in Saint Lucia's tourism and agri-food sectors.

10.4 Discussion

Results from GIRS highlight structural vulnerabilities that require a coordinated set of actions but often lead to reactive, rather than proactive, approaches to infrastructure resilience (CDRI, 2025; UNDRR, 2022). The findings show that limited human resources availability, compounded by significant brain drain, leads to reliance on external expertise and can undermine local implementation capacity. Financial constraints further exacerbate these challenges, with many SIDS remaining heavily dependent on donor funding. Consequently, resilience measures tend to be project-based, implemented only when external resources are available, which limits opportunities for systematic retrofitting or long-term planning.

The findings also highlight challenges with regulatory frameworks. Although codes and standards exist, they are often outdated, adopted from other contexts, or weakly enforced, reducing their effectiveness in promoting resilient infrastructure.

Some regional patterns emerge from the study, with results for Caribbean SIDS generally demonstrating stronger private-sector capacity, better coordination, and more accessible data, while results for Pacific SIDS point to lower human and technical capacity and weaker enforcement, despite the existence of robust frameworks on paper. Across regions, the findings indicate that donor dependence results in episodic interventions, with risk assessments, technologies, and NbS implemented primarily in response to external requirements rather than as part of a sustained, systematic approach to resilience.

Box 13

Case study: Learning from the Prioritized Road Investment and Management Enhancements Project, Federated States of Micronesia

The World Bank's $40 million Prioritized Road Investment and Management Enhancements Project, Federated States of Micronesia (FSM), approved in May 2021, sought to strengthen the country's principal road network against natural hazards and climate change (World Bank, 2021b). While the project focused on critical infrastructure to ensure safe, year-round access, its implementation highlighted important lessons for SIDS.

Effective management requires building government capacity during project preparation and using vulnerability assessments to oversee multidisciplinary teams and implement recommendations. Maintenance emerged as a key concern. Routine activities such as clearing drains, along with preventative measures such as slope stabilization, are essential to prevent costly road failures. Comprehensive vulnerability assessments depend on high-quality data, which is often limited in FSM; early engagement with coordinating ministries and the use of open-data repositories proved vital to ensure accurate analysis and long-term utility.

Procurement processes must prioritize multidisciplinary teams with balanced expertise in engineering, disaster risk management, climate science, and socio-economic assessment. Feasibility is critical. Risk assessments and modelling must be tailored to local financial and technical constraints, and road network reliability should reflect realistic stakeholder expectations.

Overall, the project demonstrates that resilient infrastructure in SIDS requires integrated capacity-building, effective data management, targeted maintenance, and context-sensitive planning to achieve sustainable, climate-resilient outcomes.

11. Limitations, Lessons Learned, and Future Directions

11.1 Limitations of the Study

As a global survey, this study has inherent limitations related to the diversity of contexts, experiences, and perspectives it captures. The findings were shaped by the participants' professional backgrounds, experience, and local context, as well as the geopolitical and cultural factors influencing interpretation, expression, and willingness to disclose information. Participation was voluntary, so the results reflect the views of those who chose to respond, potentially creating uneven representation across regions, income levels, sectors, and organization types. The analysis assumes the responses are sufficiently comparable to reveal meaningful global patterns despite variations in respondent numbers and coverage. Understanding of infrastructure resilience varies worldwide, influencing how challenges and priorities are perceived and reported. As the survey relied on self-reported assessments rather than direct measurements, differences in interpretation and potential optimism bias should be considered.

Despite these limitations, the breadth and depth of the dataset provide unprecedented insights into global trends, offering a valuable foundation for understanding systemic challenges and opportunities related to infrastructure resilience.

11.2 Lessons Learned and Methodological Improvements

The implementation of this study highlighted several lessons, suggesting methodological refinements to enhance data quality and analytical depth while preserving its global scope.

Some questions challenged respondents with specialized expertise, highlighting the need to refine framing or segment respondents by expertise. Extending survey windows would allow for more considered responses and enable follow-up with stakeholders requiring additional time to coordinate institutional inputs. Transitioning from categorical to numerical responses would support regression, correlation, and more nuanced analysis, while panel designs tracking the same respondents over multiple cycles could reveal trends and ascertain whether improvements, such as in regulatory frameworks, translate into enhanced implementation.

Global implementation partners with professional networks have proven valuable, but engaging local and regional partners could further improve reach. Local partnerships should move beyond survey dissemination to support design, implementation, and validation. This will ensure that the study frames culturally appropriate questions and arrives at contextually interpreted findings. Regional contextualization should balance global comparability, with core questions enabling worldwide analysis and region-specific modules capturing unique challenges and innovations. Integrating objective indicators alongside subjective assessments would strengthen the evidence base and help identify perception gaps.

Strengthening sampling strategies will be critical for improving robustness and representativeness. This includes increasing the number and diversity of responses by expanding outreach across regions, sectors, and under-represented stakeholder groups. Stratified sampling techniques could be introduced to ensure balanced representation of perspectives, while weighting responses may help correct for imbalances in participation.

11.3 Areas for Further Research

Future research could include sector-specific deep dives to provide technical insight while maintaining cross-sectoral comparability, with tailored questionnaires that capture implementation challenges unique to each sector. Longitudinal tracking of the same organizations and regions could measure progress over time and reveal whether improvements in policy and practice translate into higher implementation rates. Research could also investigate successful outliers to understand why some contexts achieve better outcomes despite facing similar constraints and develop case studies demonstrating how the barriers identified in the study can be overcome.

The concept of positive deviance highlights these 'bright spots', where specific strategies, leadership approaches, institutional arrangements, or cultural factors enable higher resilience implementation. Understanding transformation pathways is essential to move beyond incremental improvements. Research could examine the drivers of transformative change—including crises as catalysts, leadership, reform sequencing, and political economy factors—to identify leverage points for systemic interventions.

Justice and equity warrant further investigation through professional perspectives, as infrastructure failures disproportionately affect vulnerable populations. Future surveys could explore how practitioners perceive the distribution of resilience investments, whether current measures reduce or exacerbate inequalities, and the extent to which participatory approaches are considered or applied in planning. Questions could examine the differences in attention to gender, income, disability, and other dimensions of vulnerability, as well as the barriers professionals face in incorporating equity into resilience decisions.

Annex A. Detailed Methodology

A.1. Survey Design

The Global Infrastructure Resilience Survey (GIRS) for Infrastructure Experts and Professionals used a mixed-methods approach that combined quantitative, qualitative, and secondary data to capture both broad patterns and deeper context. This methodology helped generate robust, representative, and actionable evidence to inform the development of policies, strategies, and practices that strengthen global infrastructure resilience. The approach aimed to uncover a broad range of perspectives across regions, sectors, and organization types, as well as in-depth insights into the underlying drivers, challenges, and opportunities for building resilience in infrastructure systems. The methodology used a convergent design; that is, quantitative data and qualitative data were collected in parallel, analysed separately, and then integrated. The study design used data in the following ways:

- Quantitative data to reveal broad patterns, distributions, and relationships across a large, diverse sample of infrastructure professionals
- Qualitative data to provide nuanced explanations, uncover contextual drivers, and capture experiences and perspectives not easily quantified
- Triangulation of results from both strands to strengthen the validity, reliability, and interpretability of the findings

The survey used four, complementary sources of data:

i. **An online multiple-choice questionnaire** captured structured, comparable data from a large sample of infrastructure professionals across regions, infrastructure sectors, and organization types.
ii. **Key informant interviews (KIIs)** helped capture in-depth insights from selected experts and government stakeholders.
iii. **Focus group discussions (FGDs)** facilitated multi-stakeholder dialogues to explore diverse perspectives and foster discussion.
iv. **Secondary data** included relevant publications, datasets, and reports to contextualize and triangulate the primary data and benchmark the results against the existing evidence.

Data collection for GIRS took over several months. The online questionnaire was circulated between April and July 2025, while the KIIs and FGDs were conducted between May and August 2025. Data preparation and analysis followed the data collection.

A.2. Survey Scope and Implementation

Target Audience

GIRS engaged with a wide range of professionals involved in the delivery and governance of infrastructure systems. The survey reached out to individuals who could provide informed perspectives on both technical and institutional aspects of infrastructure resilience.

Online questionnaire respondents: The questionnaire primarily targeted professionals working on the downstream aspects of infrastructure—including construction, maintenance, operation, repairs, and use—who have a thorough understanding of how institutions, policies, and governance interact with the day-to-day practice of infrastructure operations. The focus was on ensuring that the responses reflected operational realities as well as strategic considerations.

To enhance the breadth and depth of the responses, the survey contacted a diverse range of infrastructure professionals and experts across sectors, including engineers, architects, and planners. This diversity helped provide a comprehensive picture of the challenges in and opportunities for building resilience across disciplines.

While the survey did not actively target financial and legal services professionals or students, they could respond under the 'other' category. This helped maintain inclusivity while prioritizing data from participants with directly relevant experience.

At the request of the Coalition for Disaster Resilient Infrastructure (CDRI), the study also included invited inputs from policymakers and government officials. However, these stakeholders were primarily engaged through interviews rather than the questionnaire. This was to avoid introducing government-specific questions that could increase the length and complexity of the survey, potentially reduce response rates, and complicate data analysis and interpretation.

KII and FGD participants: Participants for the KIIs and FGDs were selected based on their capacity to provide deep, context-rich insights on the institutional, technical, and operational aspects of infrastructure resilience. Participants included senior practitioners, technical experts, policy advisors, and decision-makers involved in the planning, design, delivery, operation, and maintenance of infrastructure systems. This ensured that the interviews and FGDs captured a range of perspectives from different organizational types and infrastructure sectors. Where relevant, governmental stakeholders were also interviewed, particularly to gather insights on national policy frameworks, regulatory environments, and institutional challenges. The FGDs brought together diverse stakeholder groups from different disciplines and countries to validate the emerging findings, explore differing perspectives, and identify shared priorities.

Languages and Country Outreach

The survey was made accessible to a global audience through the use of multiple languages. The online questionnaire was made available in six languages: English, French, Spanish, Portuguese, Chinese, and Arabic. This multilingual approach aimed to reduce language barriers and encourage participation by professionals from diverse infrastructure contexts across regions. To ensure meaningful engagement during the qualitative component, KIIs and FGDs were conducted in the participants' preferred languages. The KIIs were conducted primarily in English, though several interviews were held in Spanish (particularly in Latin America), a few in French, and one in Chinese; this allowed participants to express their perspectives more fully. The FGDs were held in English or in local languages with the support of translators; this

helped foster open discussion, richer dialogue, and broader participation. It also helped ensure that the participants' contributions were accurately understood.

The research applied a set of country selection criteria to maximize the likelihood of achieving CDRI's goal of covering 40–50 countries. A prioritized list of countries to conduct KIIs and FGDs in was developed based on the following characteristics: (i) existing relationships and contacts, (ii) memberships in relevant professional associations and industry bodies, (iii) languages used in the survey, (iv) country population, and (v) gross domestic product per capita. This prioritization helped direct outreach and dissemination efforts for the survey. The online questionnaire was, however, distributed globally, and diverse professionals from all countries were invited to participate, ensuring inclusivity even for those groups that were not actively targeted. Due to its voluntary nature, the survey ultimately received a variable number of responses from a much broader set of countries than initially prioritized, reflecting wide-ranging interest and engagement from diverse regions.

Pilot Testing and Implementation Partners

A pilot of the questionnaire and interview questions was conducted with a small, diverse group of participants—including the Technical Advisory Group (TAG) members—to identify and address potential issues with the questions or the technical platform. The participants in the pilot were a subset of the target audience to ensure that their feedback was representative of the broader population. The feedback covered various aspects, including the clarity and relevance of the questions, the overall length of the survey, and the user experience with the platform. The responses were analysed for patterns, such as skipped or incomplete questions, that may indicate unclear or overly complex items. Based on this feedback, adjustments were made to improve the questionnaire and the interview design.

The research team mobilized champions within the industry to promote the survey, identify interview participants, and facilitate access to potential respondents. Implementation partners included the European Council of Civil Engineers, the World Federation of Engineering Organizations, the Institute of Asset Management, the International Federation of Consulting Engineers, the Institute for Sustainable Infrastructure, the American Society of Civil Engineers, and Task Africa. In addition to these partners, individual experts with extensive networks among the GIRS target audience were subcontracted to support the distribution of the questionnaire within their professional communities.

Classification Framework

To ensure that the findings from both the questionnaire and the KIIs/FGDs could be analysed systematically and compared across contexts, a classification framework was developed. This framework allowed for analysis at multiple levels, from high-level global trend analysis to more granular disaggregation by region, income level, sector, and organization type. The analysis was structured as follows:

- **Global trends:** An initial analysis identified broad global patterns across all respondents, providing a baseline view of their perceptions on infrastructure resilience practices worldwide.
- **Organization type and infrastructure sector:** The results were further segmented:
    i. The respondents' organization type (public/private sector, as well as non-governmental organizations [NGOs], academia, and multilateral organizations)[3]
    ii. The respondents' infrastructure

sector (buildings and other infrastructure—which included transportation, energy, water and sanitation, telecommunications, emergency services and disaster response, environmental and natural resources, and waste management)

This highlighted how perspectives vary across institutional roles and technical domains.

- **Country income level analysis:** Countries were classified using the World Bank income groupings—namely, high income, upper-middle income, lower-middle income, and low income (World Bank, n.d.). This enabled comparison of responses from professionals working in different economic and resource contexts.
- **Regional analysis:** Countries were grouped following CDRI's Global Infrastructure Resilience (GIR 2023) report classification—South Asia, Europe and Central Asia, Middle East and North Africa, East Asia and Pacific, Sub-Saharan Africa, Latin America and the Caribbean, and North America. This allowed region-specific trends, challenges, and good practices to be identified.
- **Vulnerability-level analysis:** Countries were classified using the Notre Dame Global Adaptation Initiative's Country Index, an open-source tool that measures current vulnerability to climate disruptions. In this analysis, countries' vulnerability scores were grouped into three categories—low (<43.53), middle (43.53–58.05), and high (>58.05)—to enable clearer comparisons across different levels of climate risk (University of Notre Dame, 2024).

A.3. Response Rates, Number of KIIs, and FGDs

To provide context on the reach and diversity of the survey participation, the tables below present an overview of the validated questionnaire dataset, showing how responses are distributed across key categories, including region, country income level, organization type, and infrastructure sector.

Number of valid[4] responses: 2,542 out of 3,100 total questionnaire responses

Table A1

Number of responses by region

Region	No. of questionnaire responses	% Valid questionnaire responses
Sub-Saharan Africa	684	26.91
Middle East and North Africa	157	6.18
Europe and Central Asia	443	17.43
South Asia	333	13.10
North America	210	8.26
East Asia and Pacific	285	11.21
Latin America and the Caribbean	435	17.11

[4] A response was deemed valid and included in the analysis if the respondent provided essential information that allowed classification.

Table A2

Number of responses by country income level

Country income level	No. of questionnaire responses	% Questionnaire responses
High income	864	33.99
Upper-middle income	551	21.68
Lower-middle income	737	28.99
Low income	393	15.46

Table A3

Number of responses from Small Island Development States

Small Island Development States (SIDS)	No. of SIDS questionnaire responses	% SIDS questionnaire responses
SIDS (total)	142	100.00
Pacific SIDS	40	28.17
Caribbean SIDS	61	42.96

Table A4

Number of responses by organization type

Organization type	No. of questionnaire responses	% Questionnaire responses
Government	793	31.20
Private sector	1,141	44.90
Academia/NGOs/financial institutions	608	23.90

Table A5

Number of responses by infrastructure sector

Infrastructure sector	No. questionnaire responses	% Questionnaire responses
Buildings	1,843	72.50
Other infrastructure	699	27.50

Table A6

Number of KIIs by country income level

Country income level	No. of KIIs
High income	34
Upper-middle income	22
Lower-middle income	17
Low income	4

Table A7

Number of KIIs by region

Country income level	No. of KIIs
Sub-Saharan Africa	12
South Asia	3
North America	4
Middle East and North Africa	4
Latin America and the Caribbean	23
Europe and Central Asia	14
East Asia and Pacific	17

FGDs were conducted in Brazil, Egypt, Ghana, India, and Australia/Pacific SIDS.

Ethical Considerations

All data collection and analysis activities for GIRS were designed and implemented in line with internationally recognized ethical standards for research involving human participants.

- **Informed consent:** All respondents to the online questionnaire and participants in the KIIs and FGDs received clear information about the purpose of the study, how their data would be used, and their rights as participants, including the right to withdraw at any time without penalty and the assurance of confidentiality. Participants gave explicit consent through verbal confirmation prior to the interviews and FGDs.
- **Confidentiality and data anonymization:** Participants' identities and any potentially identifying information were treated as strictly confidential. Personal identifiers were removed from the datasets, and responses were anonymized during transcription and data processing. Any quotations or examples used in reporting were attributed using only generic descriptors—such as country, sector, or organization type—to prevent identification of individual respondents.
- **Data security and access controls:** All data was stored on secure, access-controlled servers. Access to raw data was restricted to core members of the research team, and data files were encrypted during storage and transfer. Version control protocols were used to track edits and prevent unauthorized alterations.
- **Sensitivity in engaging with government stakeholders:** The researchers took special care when engaging with government representatives, recognizing the potential sensitivities of sharing critical views on infrastructure resilience policies or institutional performance. Questions were framed neutrally, participation was voluntary, and responses from government stakeholders were anonymized in the same way as all other data.

A.4. Quantitative Component: The Online Questionnaire

Sampling Approach

For a finite population, sample size depends on the confidence level (which indicates the reliability of the questionnaire results, based on the likelihood that the true value falls within the confidence level), margin of error (the degree of random sampling error), and population size. A confidence level of 90 percent and a margin of error of 10 percent were initially considered for the quantitative component of the survey.

Calculating the sample size for a finite population required an assumption about the number of infrastructure professionals in each country. However, this posed several challenges. First, the definition of 'infrastructure professional' extends well beyond civil engineers to include lawyers, economists, scientists, and other experts, and there is no widely accepted or standardized definition of the term. Even if such a definition were established, no comprehensive reporting currently exists at the national or international level. Second, while some data on the number of engineers is available by country, this information is reported only for a limited subset of countries, at irregular intervals, and with varying levels of granularity. Finally, not all engineers are employed in the infrastructure sector, and the share of engineers working specifically in infrastructure varies significantly between countries. These limitations meant that establishing a robust denominator for calculating a representative sample size required careful consideration and acknowledgement of the uncertainties inherent in the available data.

Therefore, the sample size of an infinite population was determined using Cochran's (1977) formula for a 95 percent confidence level and a 50 percent population proportion. A design coefficient was applied to account for uneven responses. This resulted in a 95 percent confidence level and a margin of error between 3 and 10 percent, as shown in the tables below.

Table A8

Margin of error by region

Region	Margin of error (%)
East Asia and Pacific	6.40
Europe and Central Asia	5.19
Latin America and the Caribbean	5.21
Middle East and North Africa	9.92
North America	8.26
South Asia	5.96
Sub-Saharan Africa	4.16

Table A9

Margin of error by country income level

Income level	Margin of error (%)
High income	3.82
Upper-middle income	4.64
Lower-middle income	4.04
Low income	5.51

Table A10

Margin of error by vulnerability level

Vulnerability level	Margin of error (%)
Top third	4.20
Middle third	4.14
Bottom third	3.36

Table A11

Margin of error by organization type

Organization type	Margin of error (%)
Government	3.81
Private sector	3.17
Academia/NGOs/financial institutions	4.34

Table A11

Margin of error by infrastructure sector

Infrastructure sector	Margin of error (%)
Buildings	4.16
Other infrastructure	2.59

In practice, this meant that rather than attempting to determine a fixed total number of infrastructure professionals worldwide, the study focused on achieving adequate sample sizes within each regional and income group to enable meaningful disaggregation and comparison. This approach enabled the survey to remain statistically robust while accounting for the lack of reliable global population figures for infrastructure professionals. In addition, the sampling approach was designed to maximize diversity and representation across geographical regions, country income levels, infrastructure sectors, and organization types.

Given that the survey used an open, non-probability sampling approach (voluntary response sampling supported by targeted outreach), the focus was on reaching a large and diverse pool of respondents within each category to ensure meaningful analysis, while recognizing that the sample would not be strictly representative in a statistical sense. This approach was considered the most practical and effective way to collect global data given the available time and resources.

Questionnaire Design

Research questions were developed into a questionnaire following best practices and taking into account differences in cultural and professional backgrounds, language barriers, and regional variations. The research team recognized the need to ensure data reliability and validity across diverse contexts. The questionnaire benefited from the TAG's expertise and also incorporated the lessons learned from the 2022 GIRS (Chow & Hall, 2023).

Consistency in the language and structure of the survey was key to ensuring understanding; this was particularly so for the online questionnaire, which collected data from across the world and a range of infrastructure professionals with different backgrounds. Maintaining a neutral tone was crucial to avoid framing leading questions. Each question used clear, concise wording to reduce ambiguity. Well-defined descriptors accompanied each point on the scale, helping respondents interpret their options uniformly. Likert-type scales were used where possible to allow for nuanced responses and to extract quantitative data for analysis. Double-barrelled questions were avoided to prevent confusion and improve data accuracy. The questions had a logical flow with theme subheadings to enhance user experience.

Quantitative Data Collection

The questionnaire was distributed using SurveyMonkey. It was fully online and self-administered, allowing respondents to complete it at their convenience. The platform is mobile-compatible and accessible across devices, enabling participation from professionals worldwide regardless of location or device type.

Data collection took place between April and July 2025. This four-month window allowed sufficient time for piloting, targeted outreach, and follow-up reminders to maximize response rates and ensure balanced coverage.

Dissemination of the questionnaire link was supported by a multi-channel outreach strategy, including targeted email invitations, circulation within professional networks, and LinkedIn newsletters and posts. Implementation partners and industry champions played a central role in distributing the questionnaire, using their networks to promote participation and reach under-represented regions and sectors.

The team monitored the responses throughout the fieldwork period, tracking completion rates by region, sector, and organization type to identify any gaps in coverage. When the researchers detected under-representation in certain groups, they deployed targeted outreach efforts through relevant networks and partners to improve balance and ensure sufficient diversity in the dataset.

A.5. Qualitative Component: Interviews and FGDs

Sampling and Recruitment

The study used a purposive sampling approach to select participants for the qualitative component of GIRS. The aim was to engage professionals with substantial experience and insight into the resilience of national infrastructure systems and services, while ensuring diversity across regions, sectors, and organization types. Participants were drawn from the pre-defined list of target countries identified during the survey design phase to maximize geographical coverage and representation. Interviews were conducted initially in these target countries; the approach was subsequently adjusted to include countries where the response rate was higher and to interview representatives

from Small Island Development States (SIDS) for a more in-depth exploration of their specific infrastructure resilience contexts. In addition, five FGDs were organized in selected larger countries where sufficient numbers of relevant experts were available to support group-based dialogue.

Recruitment drew on several channels to reach suitable experts:

- Existing networks of CDRI, the International Coalition for Sustainable Infrastructure, and GIRS implementation partners;
- Professional societies and industry bodies, such as national engineering associations, infrastructure councils, and sectoral federations;
- Participants identified during related convenings (international and regional conferences, webinars, and workshops); and
- Referrals and snowball sampling from the initial interviewees to access specialized expertise in particular contexts or sectors.

Participants were selected to represent a broad range of organization types (public sector, private sector, academia, NGOs, and multilateral organizations) and infrastructure sectors. Language accessibility was prioritized to enable participation by a wider range of experts.

KII and FGD Design

The same set of semi-structured questions was used for both KIIs and FGDs to ensure comparability across all qualitative data. These questions were aligned with the main survey themes, allowing the qualitative findings to complement and strengthen the quantitative results. Questions were open-ended and neutral in wording to encourage transparent discussion, especially with government representatives.

The questions were designed to:

i. Explore the factors that influence the implementation of infrastructure resilience
ii. Identify technical, operational, and strategic considerations in infrastructure development and maintenance
iii. Uncover contextual nuances, underlying causes, and regional or cultural differences in management practices
iv. Validate or challenge the survey findings and identify gaps not covered in the questionnaire
v. Encourage reflection on broader challenges and future priorities

Qualitative Data Collection

Qualitative data were collected through KIIs and FGDs. The sessions were held remotely via Google Meet or Zoom. Participants were invited by email. They received the guiding questions in advance, which allowed them time to reflect on the topics and gather relevant examples or evidence. With the participants' permission, all sessions were recorded and transcribed for analysis, and manual notes were taken to complement the recordings.

A.6. Data Analysis Process

The qualitative and quantitative results were integrated to present a comprehensive view of participants' perceptions of infrastructure resilience. Both data types complemented each other. The online questionnaire revealed structured patterns and trends, while the interviews and FGDs supported the numerical findings with narratives to enhance reliability. The qualitative data helped explain and provide context to the quantitative findings, while the quantitative data validated and generalized the insights gained from the qualitative analysis. The quantitative method brought breadth while the qualitative methods added depth to the study, with a pragmatic focus on practical solutions rather than rigid paradigmatic constraints. To improve the robustness of the analysis, the survey findings were supplemented with secondary data. Figure A.1 presents a summary of the analysis approach.

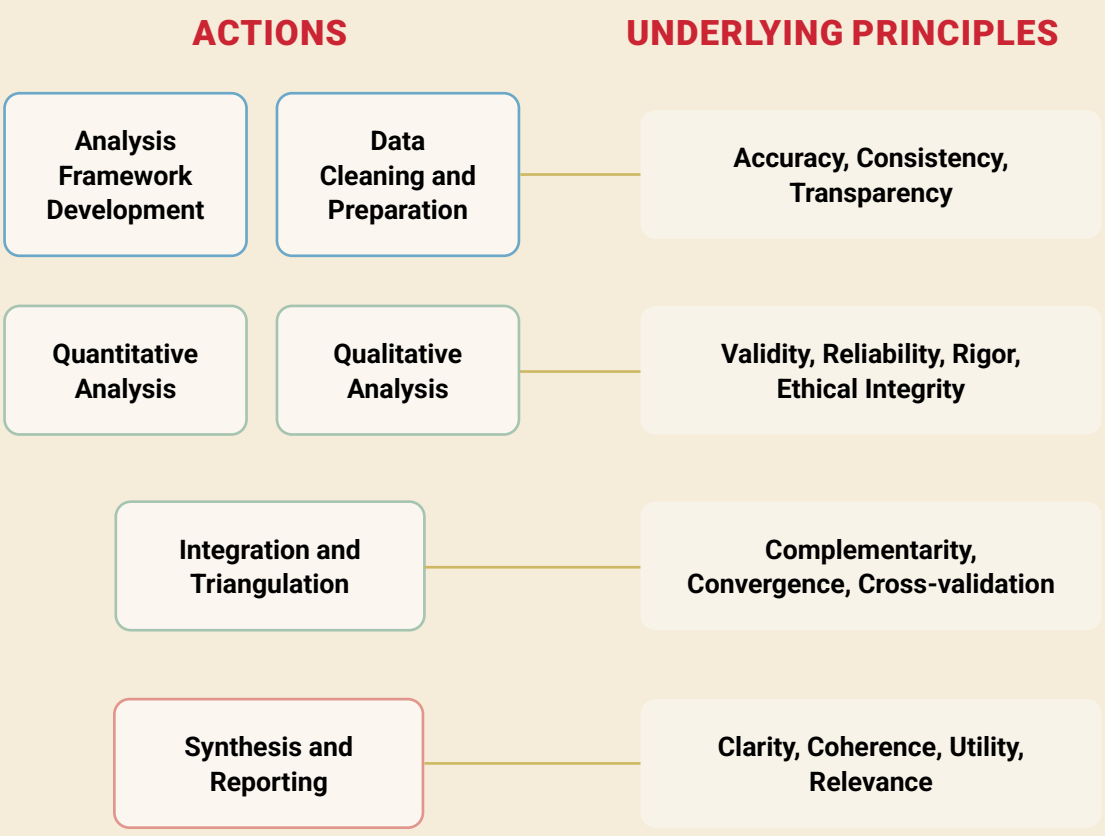


Figure A.1.

Data analysis workflow and guiding principles

Source: Authors' analysis

Step 1: Analysis Framework, Data Cleaning and Preparation

Analysis framework development: Research questions were formulated that could be consistently applied to both quantitative and qualitative data, and all questionnaire, KII, and FGD questions were mapped to this framework to ensure conceptual alignment. Key themes were defined in line with the survey structure: governance and institutions, finance, risk assessment, technology, nature-based infrastructure solutions, and monitoring systems. The framework also specified the analysis segments:

- Public sector versus private sector versus non-profit organizations
- Geographical regions
- Country income groups
- Building and infrastructure sectors

Quantitative data cleaning and preparation: The questionnaire responses were first validated and screened to remove incomplete or duplicate entries (based on response ID, timestamps, and demographic metadata). Responses were coded as numerical or categorical variables, response scales were standardized, the problem of missing data was addressed, composite variables were created where relevant, and all variables were clearly labelled.

Qualitative data cleaning and preparation: All KIIs and FGDs were transcribed, and manual notes were compiled where recordings were unavailable. Each transcript was labelled with structured metadata—including interview ID number, country, geographical region, country income level, and the interviewee's organization type (public or private sector), professional role, and infrastructure sector. The research team carried out quality checks to confirm transcription accuracy and the completeness of the metadata.

Secondary data preparation: A secondary data integration plan was developed to align external datasets with the research questions and the analysis framework. This included identifying relevant data sources, defining quality criteria—such as recency, reliability, and methodological transparency—and citing all sources systematically.

Step 2: Quantitative Analysis

The quantitative stage began with compiling descriptive statistics, calculating frequencies and percentages, producing summary statistics by theme, and generating initial visualizations. This was followed by segmentation analysis across organization type, region, income level, and sector, ensuring sufficient sample sizes for meaningful comparisons. Cross-tabulation and trend identification highlighted majorities, split opinions, or anomalies, and statistical tests were used where appropriate. Advanced techniques such as correlation analysis and factor analysis were employed to explore deeper relationships, and all potential cross-topic analyses were documented.

Step 3: Qualitative Analysis

The qualitative component of GIRS involved the systematic analysis of data collected through the KIIs and FGDs. The analysis process was designed to extract actionable insights, contextual explanations, and examples of good practices, while ensuring consistency across diverse geographical, sectoral, and organizational contexts. The qualitative analysis process involved the following steps:

Development of structured KII and FGD summaries: For every KII and FGD, structured summaries were developed to answer the 12 core interview questions. This involved first manually reviewing the transcript to extract clear responses to each question and then using an artificial intelligence (AI) tool to summarize the responses in line with the same 12-question framework. The two

sets of summaries were then synthesized into a single structured output, resolving discrepancies and noting where questions were only partially addressed.

Primary fact-checking: All the summaries were reviewed for accuracy and completeness. Clarifying comments were added where necessary, and uncertain or potentially inaccurate points were flagged for further validation.

Thematic coding: First, 32 key data points were identified based on the five core thematic areas of the survey: governance, finance, risk assessments, nature-based solutions, and advanced technology.

- Each data point was then assigned deductive (framework-based) codes to ensure consistency and comparability across KIIs and FGDs.
- The structured KII and FGD summaries were reviewed to extract these key data points, which were then assigned codes within the relevant thematic area. A short narrative explanation was added to each coded data point to capture contextual details and nuances.
- Coding was carried out using both manual review and AI tools to increase consistency, reduce human error, and speed up processing.
- Concrete examples, such as projects, policies, or initiatives, were also tagged within the relevant thematic area, and positive examples and potential good-practice cases were flagged during this stage.

Secondary fact-checking: The coded outputs and extracted examples were subjected to a second round of review to verify factual accuracy, coding consistency, and correct attribution of quotes or examples. Discrepancies were resolved by referring to the original transcripts, and flagged items were validated through triangulation with secondary sources or follow-up clarifications with interviewees where feasible.

Pattern and comparative analysis: The final coded dataset was analysed to identify recurring patterns, points of convergence or divergence, and notable outliers. Responses were compared across regions, income groups, organization types, and infrastructure sectors to highlight systematic differences or shared challenges. Illustrative quotations and case examples were incorporated to support key findings. The analysis also aimed to identify promising or innovative practices that could serve as potential case studies for further validation and inclusion in the reporting phase.

Step 4: Integration and Triangulation

The integration and triangulation stage brought together the different evidence streams—quantitative data from the online questionnaire, qualitative insights from the KIIs and FGDs, and relevant secondary data—to produce a coherent and comprehensive set of findings.

Integration was carried out theme by theme, following the six thematic areas of GIRS. For each theme, statistical patterns and trends were analysed first, providing an overview of how widespread or significant certain views or practices were. Qualitative evidence was then layered on top of these results, offering explanations, contextual details, and illustrative examples that helped interpret and provide depth to the quantitative patterns.

Convergences and divergences between the qualitative and quantitative results were explicitly documented. Areas of convergence, where both types of data pointed to the same conclusions, strengthened confidence in the findings. Areas of divergence, where the data types suggested different or conflicting conclusions, were analysed in depth to understand the possible reasons for the discrepancy (e.g., regional or organizational differences, cultural factors, or framing effects in the survey questions).

Secondary data (including published reports, statistical datasets, and policy documents) was incorporated to validate, benchmark, and contextualize the primary findings. This triangulation process ensured that all the key messages were supported by at least two independent lines of evidence.

The integration process was iterative. If unexpected themes or anomalies emerged during synthesis, the team revisited the original data to check for coding errors, sampling effects, or unconsidered contextual factors. These results were also cross-checked against external sources to ensure reliability and accuracy.

Step 5: Synthesis and Reporting

Following integration, the findings were synthesized into a cohesive set of outputs, combining the breadth of the quantitative evidence with the depth of the qualitative insights and the credibility of secondary data sources.

Good-practice case studies were identified as part of this synthesis. Selection criteria included geographical and income-group diversity, hazard type, sectoral coverage, and the degree of innovation demonstrated. Each proposed case was verified using secondary sources and documented in a concise, structured, and replicable format to facilitate comparison and potential future uptake.

Comparative analyses, supported by AI-assisted tools, were used to systematically highlight differences and commonalities across regions, income groups, organization types, and sectors.

For each of the six thematic areas, the team developed a set of key messages that comprised:

i. Headline quantitative findings

ii. Explanatory qualitative insights

iii. Validation from secondary data

iv. Observed regional or income-level variations

Before finalization, a second round of fact-checking was done to verify all the statistics, quotes, and case study details.

A.7. Limitations of the Methodology

While GIRS employed rigorous methods to ensure the quality and reliability of the findings, several limitations should be acknowledged:

- **Sampling and representativeness:** The survey used purposive sampling, prioritizing respondents with relevant expertise rather than producing a statistically representative sample of all infrastructure professionals. Consequently, the findings reflect expert perspectives rather than the views of the broader population. The population size of infrastructure professionals is largely unknown, and the broad definition of 'infrastructure professional' further limits sampling precision.
- **Response and self-reporting biases:** As with all self-reported data, responses may reflect participants' personal perspectives, professional interests, or socio-cultural desirability tendencies. Respondents may over-emphasize positive practices or under-report challenges. Self-reported assessments, unlike direct measurement, may introduce optimism bias and differences in interpretation across respondents.
- **Regional, sectoral, and voluntary participation skew:** Participation varied across regions, country income levels, infrastructure sectors, and organization types, with higher engagement from areas where existing networks or implementation partners had stronger reach. Further, voluntary participation means certain voices may be over- or under-represented, influencing the balance of perspectives.

- **Contextual and cultural influences:** Responses are shaped by each expert's professional background, experience, and context. Cultural values affect how questions are interpreted, including perceptions of risk and political sensitivities, which may affect comparability across countries.
- **Language and translation limitations:** Although the FGDs and interviews were conducted in multiple languages with translation support, subtle nuances may have been lost, potentially affecting the depth or accuracy of the qualitative responses.
- **Statistical constraints and comparability:** Questions were structured as categorical variables aligned with the CDRI thematic areas, which limits the scope for advanced statistical analysis. Significant gaps due to unanswered questions and uneven respondent representation call for cautious interpretation of aggregated differences across regions, income groups, and sectors. Analyses assume that respondents answered candidly and that regional comparisons are broadly meaningful despite these limitations.
- **Mitigation measures:** To address these challenges, several steps were taken: targeted outreach to under-represented groups, provision of the questionnaire in multiple languages, advance dissemination of interview questions, use of a structured analysis framework for consistency, triangulation of findings with secondary data, and multiple rounds of fact-checking and stakeholder validation to reduce errors and confirm key conclusions.

Annex B. Survey Questions

Online Questionnaire Questions

KII and FGD Questions

1. How would you describe the institutional capacity of infrastructure ministries and agencies for supporting the implementation of resilience?
    1.1. What is the human resources availability in ministries to support resilience?
    1.2. Are there any sectors ahead of others?
    1.3. Give examples of when the government demonstrated capacity for supporting resilience and examples of gaps.
    1.4. What is the priority area for strengthening capacity?
2. How would you describe the private sector's subject matter expertise and human resources availability to support the implementation of resilience?
    2.1. Give examples of when the private sector demonstrated capacity for supporting resilience and examples of gaps.
    2.2. How can the public sector better engage with the private sector to strengthen infrastructure resilience?
3 How effective is the coordination between disaster risk management agencies and infrastructure-related organizations in disaster preparation, response, and recovery?
    3.1. Give examples for areas of improvement.
4. What regulations, codes, and standards for infrastructure resilience exist?
    4.1. Provide examples of existing regulations that include resilience.
    4.2. Provide examples of existing codes and standards that include resilience.
    4.3. What are the key gaps in regulations, codes, and standards?
    4.4. Are international standards adopted in the absence of national standards and codes?
    4.5. Is risk modelling for infrastructure design included in codes and standards, and for which sectors? Give examples, as well as for challenges and barriers to use.
    4.6. What enforcement mechanisms exist, and are these effective and consistent across sectors and regions?
5. Is government funding for infrastructure resilience adequate to make assets resilient (to today's disasters and future climate change impacts)?
    5.1. Are some regions or infrastructure sectors prioritized for funding?
    5.2. If not adequate, where are the funding gaps in allocation mechanisms?
    5.3. What types of projects or interventions are prioritized (e.g., new infrastructure, retrofitting programmes, maintenance, or post-disaster reconstruction)?
    5.4. Provide examples from different regions and sectors.
    5.5. Can you point out any national or targeted retrofitting programmes designed to improve the resilience of existing infrastructure? What improvements were made, and are they effective?
6. What are the finance mechanisms that are being used to finance resilience (e.g., public–private partnership [PPP] contracts with strong resilience clauses, thematic bonds, or insurance)?

6.1. Are PPPs being used to finance infrastructure resilience? How effective is the risk and responsibility allocation? Provide examples.

6.2. How well do these financial mechanisms address disaster and climate risks (e.g., PPP contracts with strong resilience clauses, thematic bonds, and insurance)?

6.3. How effectively does government funding align with 'build back better' principles?

7. How are climate and disaster risk assessments used in infrastructure development?

7.1. Are climate risks consistently included in risk assessments?

7.2. Are climate and disaster risk assessments embedded in decision-making processes?

7.3. Are some sectors more advanced than others?

8. Is data available to support climate and disaster risk assessments?

8.1. Is data for hazard, vulnerability, and risk assessments available, and is it reflective of current hazard and vulnerability conditions? Is it collected frequently enough and for all hazards? Provide examples.

8.2. Are there specific data gaps by hazard, location, or infrastructure sector? How can they be addressed?

9. How are nature-based solutions (NbS) used to enhance the resilience of infrastructure?

9.1. Which infrastructure sectors most commonly use NbS?

9.2. Give examples of the types of NbS available for infrastructure used across sectors and regions.

9.3. Are they well integrated (with grey infrastructure), maintained, and supported (by agencies)?

10. If and when NbS are used, how well are they financed, implemented, and supported in the long term?

10.1. What/who is driving adoption where NbS are used?

10.2. What are the barriers to scaling NbS (technical, financial, institutional, or cultural)?

11. What new technologies do infrastructure sectors use to strengthen the resilience of infrastructure assets, systems, and users?

11.1. Which sectors are leading in the adoption of technologies that enhance resilience?

11.2. Give examples of projects.

11.3. What drives adoption in specific sectors?

11.4. What are the challenges to implementation (e.g., cost, capacity, or trust)?

12. What should be the government's top priority for making infrastructure more resilient over the next 5–10 years? How can the private sector help?

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