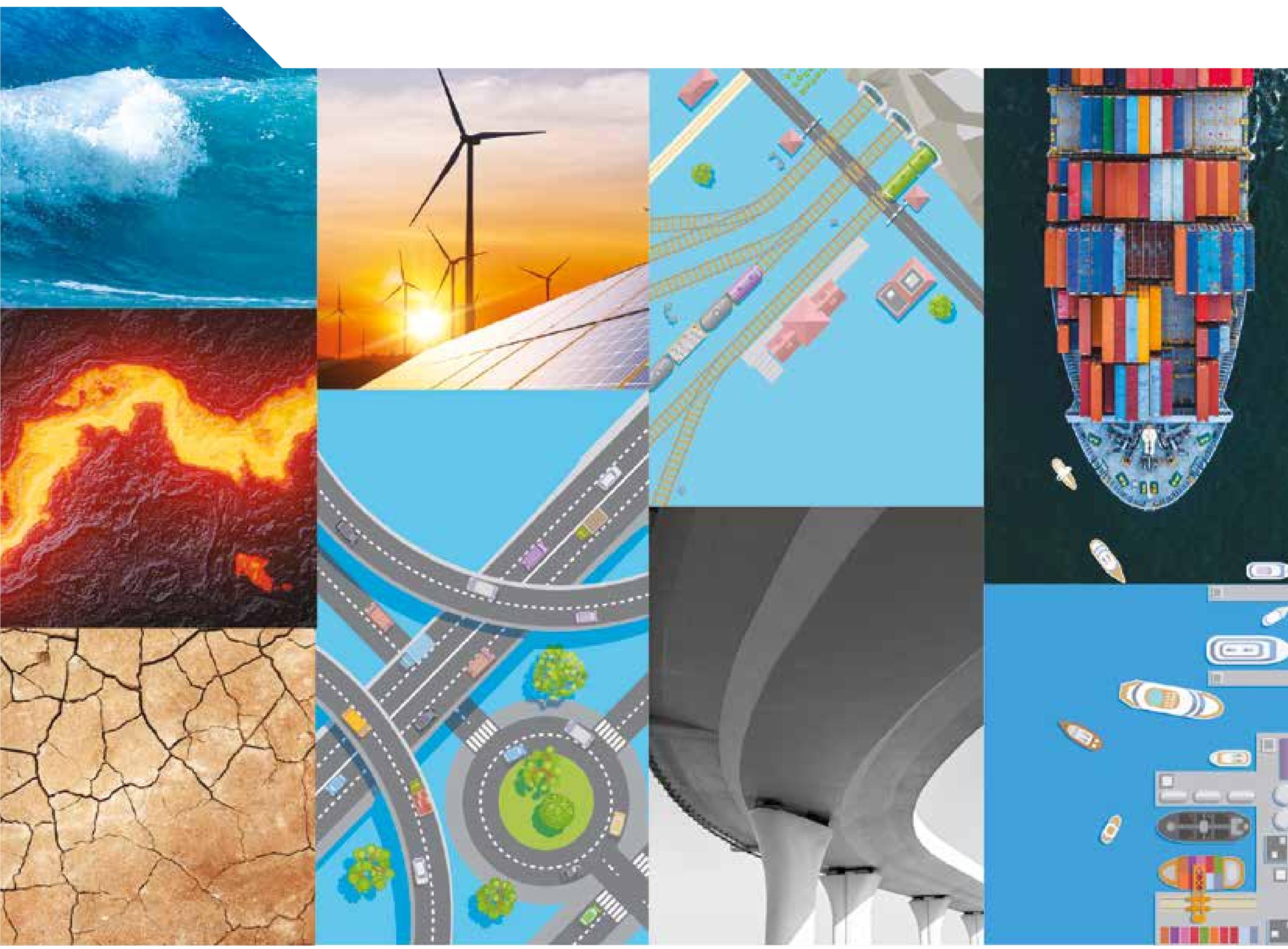
Compendium of Good Practices on Quality Infrastructure 2024

BUILDING RESILIENCE TO NATURAL DISASTERS



OECD DEVELOPMENT CENTRE

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Foreword

In 2019, the G20 endorsed the G20 Principles for Quality Infrastructure Investment, emphasising the need for projects that are economically viable, socially inclusive, environmentally sustainable and resilient to natural disasters. By adhering to these principles, policy makers and investors can ensure that infrastructure investments not only drive economic growth but also contribute to broader societal well-being and environmental stewardship.

This new Compendium of Good Practices on Quality Infrastructure is the result of a collaboration with the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan. By reviewing concrete infrastructure projects implemented in OECD member countries as well as in other economies in Africa, Asia, Latin America and the Caribbean, it aims to help stakeholders all over the world to learn from their diverse experiences.

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Editorial

Hurricanes battering coastal regions, wildfires ravaging vast areas of land and seismic upheavals wreaking havoc on urban centres: recent events have been highlighting the vulnerabilities inherent in our current infrastructure systems. Such challenges call for innovation and adaptation, not only to mitigate the impacts of natural disasters but also to pave the way for long-term sustainability and prosperity. The findings of this report will help policy makers, engineers and stakeholders embrace a proactive, concerted approach to reach those goals: a timely contribution to actions towards a safer, more sustainable future for all.

The report underscores the critical importance of investing in infrastructure that can withstand the forces of nature. Based on the experiences of diverse nations, from Japan to Colombia and the United Sates, from Mozambique to Ghana, India and Indonesia, it proposes actions to implement the G20 Principles on Quality Infrastructure. While every region and country face a unique set of challenges, studying the successes and failures of others opens up a wealth of knowledge that can usefully inform action by all.

Our case studies from around the world provide valuable insights into the diverse array of strategies and solutions to enhance infrastructure resilience. Whether it be Japan's capacity to implement strategic preventive maintenance or Ghana's capacity to restore power plants' operations in the aftermath of floods, a wealth of best practices is waiting to be shared and adapted to local contexts.

In collaboration with the Japanese Ministry of Land, Infrastructure, Transport and Tourism, the Development Centre is publishing this new *Compendium* to help developing countries plan, build, maintain and operate the resilient infrastructure that may serve as a barricade against the storms of tomorrow.

Ragnheiður Elín Árnadóttir

Director

OECD Development Centre

Table of contents

FIGURES

TABLES

BOXES

Abbreviations and acronyms

AI	Artificial Intelligence
ATMS	Automatic Traffic Management System
BSP	Bulk Supply Point
DBE	Design Basis Earthquake
DFIs	Development Finance Institutions
DKI Jakarta	Provincial Government of the Special Capital Region of Jakarta
DPS	Disaster Prevention System
EPA	Environmental Protection Agency
EU	European Union
EWS	Early Warning Systems
GIS	Geographic Information Systems
GRIDCo	Ghana Grid Company
HFL	High Flood Level
ICT	Information and Communication Technology
IDB	Inter-American Development Bank
IoT	Internet of Things
JICA	Japanese Development Cooperation Agency
LAC	Latin America and the Caribbean
LDCs	Least Developed Countries
MDBs	Multilateral Development Banks
MFDA	Metro Flood Diversion Authority
MHEWS	Multi-Hazard Early Warning System
ML	Machine Learning
MLIT	Japanese Ministry of Land, Infrastructure, Transport and Tourism

MMS	Mobile Mapping System
MRT	Mass Rapid Transport
MVA	Mega Volt Amp
NBS	Nature-Based Solution
NDBs	National Development Banks
NGOs	Non-Governmental Organisations
OECD	Organisation for Economic Co-operation and Development
PABs	Private Activity Bonds
PPA	Project Partnership Agreement
PPPs	Public-Private Partnerships
RAMP	Road Asset Management Platform
RPM	Regular Preventive Maintenance
RRIF	Railroad Rehabilitation and Improvement Financing
RRVA	Red River Valley Alliance
SADC	South African Development Community
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
TOD	Transit Oriented Development
UF	Functional Unit
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
USACE	United States Army Corps of Engineers
USDOT	US Department of Transportation

Executive summary

As climate change continues to alter natural hazard patterns, ensuring infrastructure resilience to natural disasters emerges as a global priority. This requires strengthening the prevention, reaction and rebuilding capacities of governments, the private sector and civil society. In such an endeavour, technology, collaboration and data emerge as linchpins, as they determine the quality of prevention, reaction and re-building efforts. In turn, adequate financing and investment, technical expertise and regulatory frameworks shape the effectiveness of preparedness and responses.

Based on concrete infrastructure projects in Colombia, Ghana, India, Indonesia, Japan, Mozambique and the United States, this compendium identifies seven global practices with universal relevance to make infrastructure resilient to natural disasters:

- Adopt a life-cycle approach and factor in resilience throughout the entire lifespan of projects, from planning and design to operation and maintenance.
- Align interests through effective collaboration among stakeholders to ensure collective action towards resilience goals.
- Conduct comprehensive risk assessments to identify vulnerabilities and develop robust mitigation strategies.
- Measure impacts to understand the consequences of natural disasters and guide informed decision making.
- Invest in capacity building and knowledge management to empower individuals and organisations with the skills and information needed to plan, implement and operate resilient infrastructure.
- Carry out strategic preventive maintenance to increase the lifespan of infrastructure assets and ensure resilience.
- Deploy cutting-edge technology and foster innovation in design to enhance infrastructure resilience and adaptability to changing environmental conditions.

For each good practice, the compendium presents concrete implementation guidance, taking into account the specific challenges of developing countries, which are disproportionately affected by the heightened risks of climate change and natural disasters. Small Island Developing States (SIDS) and least developed countries (LDCs) are among the most vulnerable due to their geolocation, economic structures, poor infrastructure, limited financial capacities and a general lack of technical skills and access to early warning systems. Increased international partnerships and enhanced support from development banks – through financing, risk assessment and project preparation – are thus necessary to support infrastructure resilience in developing countries and enable them to implement global good practices.

1 Ensuring infrastructure resilience to natural disasters is a global priority

As climate change continues to alter natural hazard patterns, there is an urgent need to strengthen infrastructure resilience to natural disasters. Technology, data and collaboration, enabled by adequate financing, investment, technical expertise and regulatory frameworks, are key to increase prevention, reaction and rebuilding capacities. While building resilience to natural disasters is a global challenge, developing countries, particularly Small Island Developing States (SIDS) and Least Developed Countries (LDCs) are among the most vulnerable and require targeted support. Increased international partnerships and enhanced efforts from development banks are imperative to bolster infrastructure resilience in developing countries and support their journey towards sustainable development.

Introduction

Natural disasters are extreme events caused by natural processes of the Earth. They include phenomena such as earthquakes, tsunamis, hurricanes, tornadoes, floods, wildfires, volcanic eruptions, landslides and droughts. These events are characterised by their sudden onset and unpredictability, making preparedness, mitigation, and response efforts essential for minimising their impact on the economy and society.

In the absence of effective prevention, reaction and rebuilding capacities, these events can result in significant damage to existing assets and impact on human lives, profoundly affecting the economy and society. Often, it is the poorest people and areas that endure the most severe consequences.

This introductory chapter of the *Compendium of Good Practices on Quality Infrastructure 2024* outlines the global priority of considering resilience to natural disasters in infrastructure projects. It underscores the relevance and urgency of this issue, particularly in developing countries and it provides a framework to guide policy actions aimed at ensuring infrastructure resilience to natural disasters.

This edition of the Compendium focuses on competitiveness-related infrastructure (e.g. transport and digital networks, energy systems) (Box 1.1). This choice is due to two main reasons: first, these infrastructures play a pivotal role in enabling growth and in shaping the economic attractiveness and development potential of a given location in national, regional and international markets; second, both advanced and developing economies face major pressures to upgrade and update these infrastructures. In particular, advanced economies need to upgrade their existing infrastructure to make it resilient to natural disasters. Conversely, developing countries face the pressure to close their infrastructure gaps to sustain their development and industrialisation aspirations. It is essential to undertake this task in a way that prevents them from being locked-in to poor-quality infrastructure, with limited capacity to withstand the growing impact of natural disasters.

Box 1.1. Defining competitiveness-related infrastructure

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

Source: Authors' elaboration.

Competitiveness-related infrastructure plays a crucial role in determining international competitiveness and local development opportunities. Ensuring that competitiveness-related infrastructure is resilient to climate change and to natural disasters is essential to foster sustainable growth, business development, foreign direct investment, innovation, and a seamless flow of goods and services.

This chapter is structured in three sections. The first outlines the growing risks associated with natural disasters, the second identifies the three areas in which governments, the private sector and civil society need to develop capabilities to ensure infrastructure resilience to natural disasters: prevention, reaction and re-building. The third section identifies the drivers and enablers of preparedness and response efforts, notably: data, collaboration and technology, enabled by adequate financing, investment, technical expertise and a comprehensive regulatory framework.

Natural hazards are rising in frequency and intensity

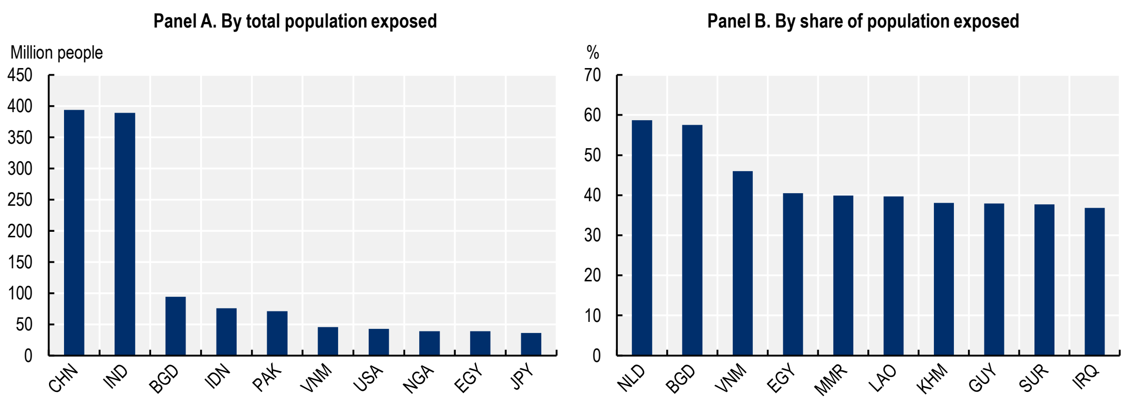
The world is witnessing an increase in the frequency and intensity of natural hazards, mostly due to climate change, which is affecting extreme weather event patterns across the globe. The number of reported natural disasters more than doubled during 2000-19 compared to the previous two decades (UNDRR, 2020[1]). In Japan, the Japan Meteorological Agency has documented a notable increase in the frequency of heavy rain events, partly attributed to the rise in sea surface temperatures (JMA, 2023[2]). Notably, flood damage statistics, particularly in 2019, surged to a record high, amounting to JPY 2 180 billion (Japanese Yen) (USD 16.5 billion) (MLIT, 2021[3]). This figure underscores the pressing need for resilient infrastructure capable of mitigating the adverse effects of such disasters.

While the rise in frequency and intensity of natural hazards is growing globally, developing countries are particularly affected due to the compound effect of multiple factors.

- **Geographic vulnerability.** Many developing countries are located in regions prone to climate-related hazards, such as coastal areas susceptible to hurricanes and typhoons, or regions prone to floods, droughts, hurricanes and heatwaves, which are exacerbated by climate change (Figure 1.1).

Figure 1.1. Developing countries are particularly exposed to floods, 2020

Top 10 countries with highest exposure to floods, by exposed population and by share of exposed population to national total, 2020

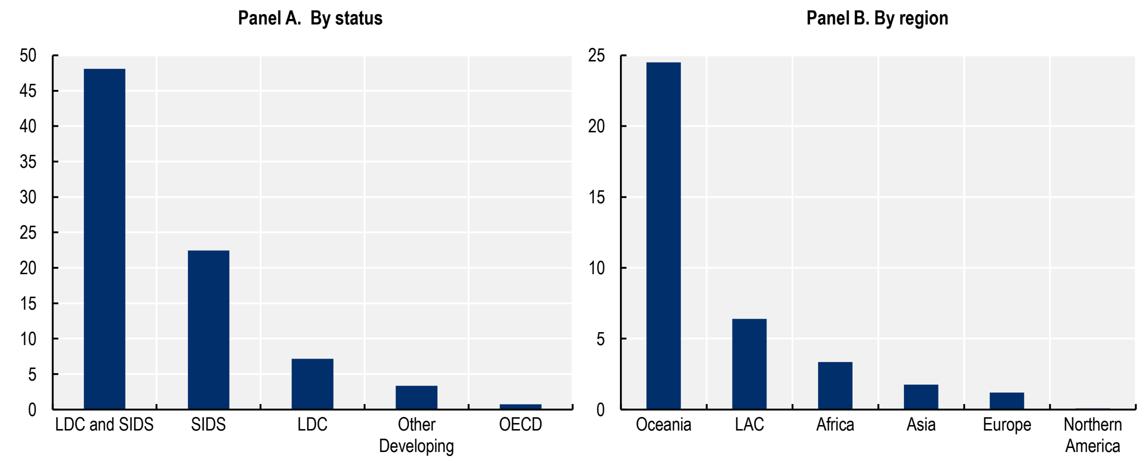


Note: People directly exposed to inundation depths of over 0.15 meters in the event of a 1-in-100-year flood. It considers people's exposure to all current flood risks—that is, pluvial, fluvial and coastal flooding.
Source: Authors' elaboration based on Rentschler, Salhab and Jafino (2022[4]), *Flood exposure and poverty in 188 countries*, https://doi.org/10.1038/s41467-022-30727-4

- **Climate change vulnerability.** Among the developing countries, Small Island Developing States (SIDS) and Least Developed Countries (LDCs) are those most severely affected by climate change (IPCC, 2022[5]). Between 2000 and 2020 SIDS and LDCs exhibited an average of 23 and 7 natural disasters per 1 000 square kilometres, respectively (Figure 1.2). This translates to between 10 and 30 times more disasters compared to OECD countries.

Figure 1.2. SIDS and LDCs have the highest global exposure to climate change and natural disasters

Average number of natural disasters per 1 000 sq Km, 2000-20

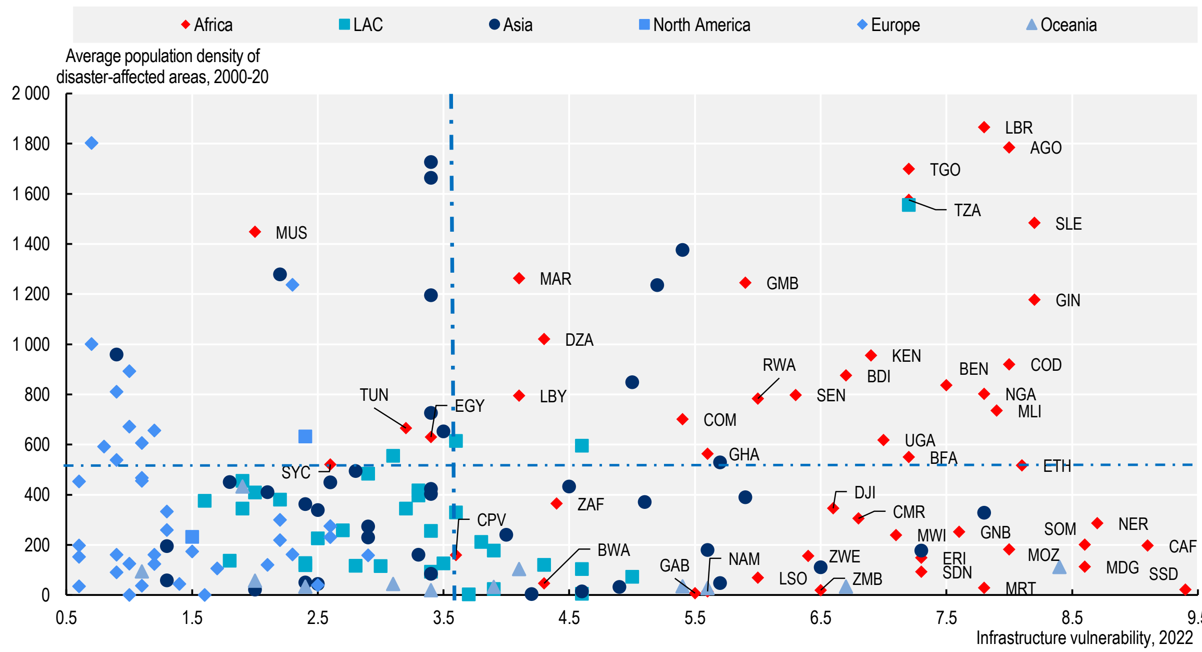


Note: Panel A. 1) The categories are not mutually exclusive 2) Other Developing countries include all DAC recipient countries that are non-LDCs including low middle-income and upper middle-income countries. Analysis follows the UN Geographical and Income Classification System https://unstats.un.org/unsd/methodology/m49/.
Source: Authors' elaboration based on EM-DAT (2023[6]), *International Disaster Database*, https://www.emdat.be/ and World Bank (2023[7]), *World Development Indicators*, https://data.worldbank.org.

- **Economic vulnerability.** Developing countries tend to be **dependent on sectors and activities highly influenced by natural disasters. For instance,** they rely heavily on climate-sensitive sectors such as agriculture, fisheries, forestry and tourism. Natural disasters, exacerbated by climate change, can strongly affect these sectors, leading to food insecurity, loss of income and economic instability.
- **Poor infrastructure.** The vulnerability of developing countries to natural disasters is exacerbated by the high population density of the most affected areas and poor infrastructure. This is particularly evident in Africa where natural disasters occurred in areas with high or very high infrastructure vulnerability, as measured by the European Commission's INFORM index (Figure 1.3). Climate-resilient infrastructure is in even shorter supply in developing countries. This is infrastructure that is planned, designed, constructed and operated in a way that anticipates, prepares for and adapts to the changing climate, while it can withstand and recover rapidly from disruptions caused by changing climatic conditions throughout its entire lifetime. It concerns new assets and existing ones, which may need to be repurposed or operated differently to account for climate change impacts (OECD, 2018[8]).

Figure 1.3. Poor infrastructure coupled with population density increases vulnerability to natural disasters

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



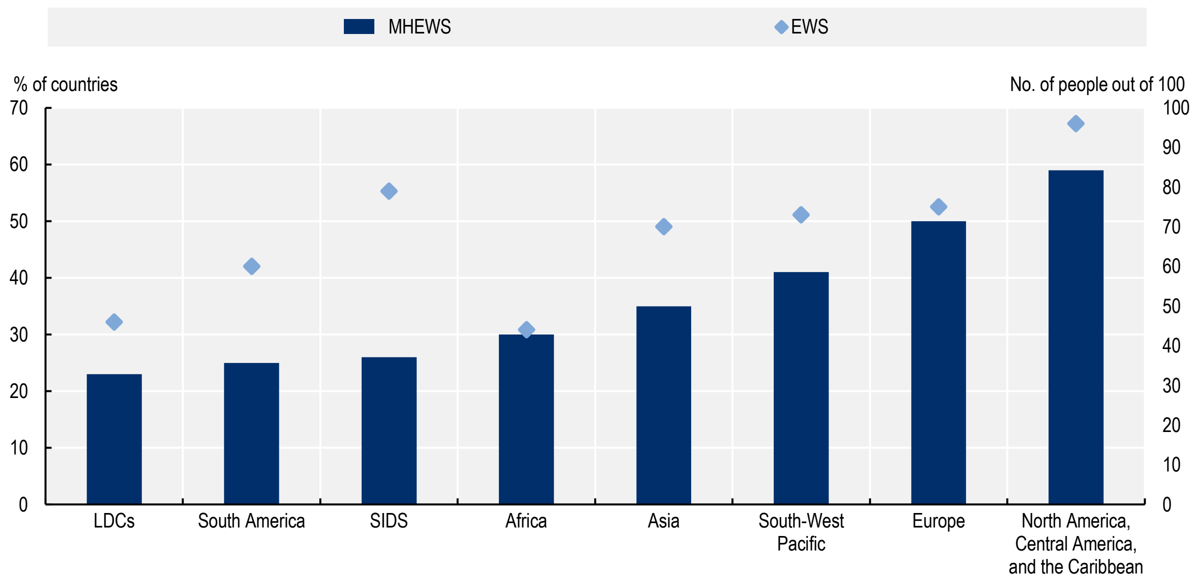
Note: The dotted lines reflect the global averages of the respective variables. The average population density is calculated within a 1 km radius of the disaster event. Infrastructure vulnerability is the normalised arithmetic average of three categories that give equal weight to 11 indicators including: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

Source: OECD/UN/UNIDO/ITC (forthcoming[9]), *Production Transformation Policy Review of Togo*, based on INFORM GRI 2022: Index for Risk Management. European Commission 2022, https://drmkc.jrc.ec.europa.eu/inform-index and SEDAC Gridded Population of the World, Version 4 (GPWv4), https://cmr.earthdata.nasa.gov/search/concepts/C1597158029-SEDAC.html.

- **Limited access to early warning systems.** Most developing countries lack access to timely and accurate climate information and early warning systems, hindering their ability to prepare for and respond to natural disasters. Inadequate infrastructure and limited institutional capacity to address risks upfront and react to disasters, coupled with high population density of the areas most affected by climate change-related natural disasters further impede effective disaster risk management. Developing countries have limited capacities in the use of early warning systems (EWS) and multi-hazard early warning systems (MHEWS). MHEWS address multiple hazards simultaneously and are key to increasing countries' prevention capacities. Only 11 LDCs have a MHEWS in place, and 46 out of 100 people are covered by EWS. In terms of regions, South America has the lowest share of countries reporting the existence of a MHEWS (25%), followed by Africa (30%) (Figure 1.4). Innovative technologies can further maximise the investments in EWS infrastructure. For instance, artificial intelligence (AI) can assist in developing early warning systems for extreme weather events, enabling better preparedness. In particular, EWSs can help in identifying and assessing vulnerabilities in communities and infrastructure, provide real-time information on weather patterns, and improve the accuracy and precision of climate models, allowing for more effective policy responses (Jain et al., 2023[10]).

Figure 1.4. Developing countries lag behind in access and use of early warning systems (EWS)

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



Note: EWS: Early warning systems; MHEWS: Multi-hazard early warning systems.
Source: Adapted from WMO (2020[11]), *2020 State of Climate Services: Risk Information and Early Warning Systems*, WMO-No. 1252.

- **Financial constraints.** Developing countries face important resource shortages and the cost of access to capital is relatively higher for them, hindering their ability to build quality infrastructure (OECD, 2022[12]; Lardé, 2021[13]; ICA, AfDB and NEPAD-IPPF, 2022[14]). Closing the financing gaps for quality infrastructure in developing countries is crucial to build, adapt and operate the necessary infrastructure to support their development in a forward-looking manner. Targeting investment to the right areas and projects, and mobilising private resources will be crucial to advance towards sustainable, inclusive and resilient growth models.

Preventing, reacting and re-building capacities are key areas to ensure infrastructure resilience to natural disasters

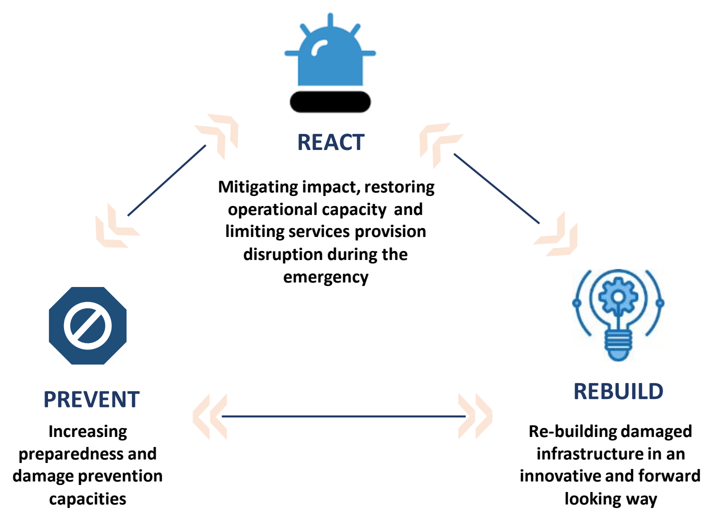
As the intensity and frequency of natural disasters increases, it is of pivotal importance to increase infrastructure resilience to natural hazards (OECD, 2024[15]). Governments, the private sector and civil society will have to pay attention to three key and interconnected areas (Figure 1.5):

- **Preventing**: This area is linked to actions, tools and physical characteristics of the infrastructure that enable damage prevention and/or minimisation of the impact of natural disasters, including disaster risk assessments from the early stage, disaster risk management, early warning systems, social safety nets, strategic preventive maintenance as well as structural measures and novel infrastructure designs, including construction of levees for flooding. Increasing anticipation capacities in governments is a key factor, as current modelling tools need to be updated to take into account the impacts of climate change.
- **Reacting:** This area is linked to the actions taken and tools used in response to a natural disaster to restore operational capacity and mitigate service provision disruption, by providing short-term

countermeasures such as alternative infrastructure options and services. This also includes regulatory and economic instruments that facilitate the implementation of disaster risk management in a timely manner, including access to emergency finance for the swift recovery of social and economic functions and services to minimise the severity and duration of disruption.

- **Re-building:** This area is linked to actions, tools and plans, including changes in the physical characteristics of the infrastructure that shape how the disrupted infrastructure is rebuilt in effective, efficient and forward-looking ways. It also includes the building of new infrastructure assets, as well as the repurposing of existing infrastructure done in a forward-looking and disaster-resilient way. This includes deployment of advanced, efficient and low-emission technologies, changes to infrastructure design, actions to protect and restore ecosystems and new forms of stakeholders' engagement to ensure that re-building efforts go beyond the traditional restoration logic and allow for innovation and improvements in resilience, access and quality of the infrastructure.

Figure 1.5. A three-pillar action framework for infrastructure resilience to natural disasters

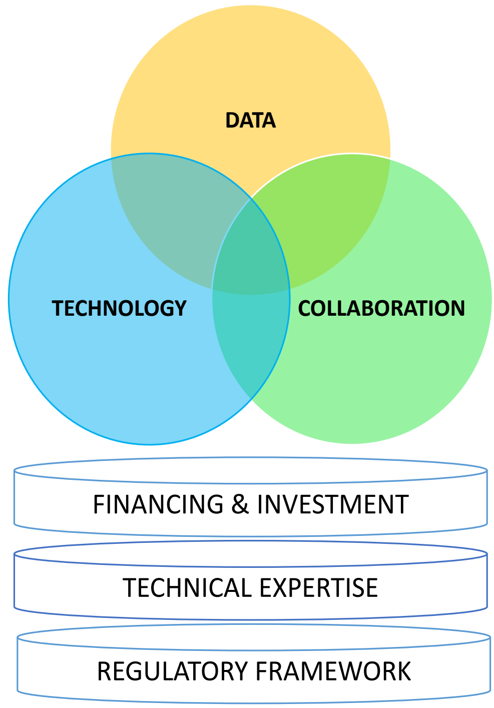


Source: Authors' elaboration.

Collaboration, data and technology shape the effectiveness of prevention, reaction and rebuilding efforts

Three factors are pivotal in determining the effectiveness of prevention, reaction and re-building efforts: collaboration, data and technology. These factors are highly context-specific and are enabled by adequate financing and investment, technical expertise, and regulatory frameworks (Figure 1.6). Together these drivers and enablers form the foundation for building infrastructure resilience to natural disasters. By ensuring adequate funding, harnessing technical knowledge and skills, and implementing robust regulatory frameworks, communities can best leverage on collaboration, technology and data to develop infrastructure that is better able to withstand and recover from the impacts of natural disasters, ultimately enhancing the safety, sustainability and resilience of their economic development pathways.

Figure 1.6. Drivers and enablers of prevention, reaction and re-building efforts



Source: Authors' elaboration, based on the discussions held during the 2nd preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Planning, Financing, and Building Infrastructure Resilient to Natural Disasters that took place on 7 September 2023.

Collaboration enables the mobilisation of funding sources and technical assistance through partnerships, reduces the financial burden on individual stakeholders, and facilitates the transfer of knowledge and best practices. Moreover, clear allocation of responsibilities across actors ensures streamlined decision-making and implementation processes, leading to more robust and adaptive infrastructure systems. Effective collaboration among stakeholders from diverse sectors and countries is essential for pooling resources, sharing expertise, and co-ordinating efforts to enhance prevention, reaction and re-building efforts (Box 1.2).

Technology shapes resilience in preparation, construction, operation and maintenance. New materials influence infrastructure resilience. Digital technologies enable advanced monitoring, real-time data analytics and predictive capabilities that can help identify vulnerabilities, assess risks and respond swiftly to emerging threats. Through the integration of smart technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML), infrastructure becomes more adaptive and self-modifiable, capable of autonomously responding to changing environmental conditions and potential hazards (Box 1.2).

Data, underpinned by high-quality information and analysis, serves as the bedrock for informed decision making and proactive risk management. Comprehensive data collection mechanisms and analytical tools enable stakeholders to assess the potential impact of natural disasters, identify relevant uncertainties, and incorporate risk factors into infrastructure planning and design. Access to timely and accurate data empowers stakeholders to anticipate challenges, develop effective prevention and response strategies, and optimise resource allocation for resilience-building efforts. By harnessing the power of collaboration, technology and data, infrastructure can be fortified to withstand and recover from various natural disasters, safeguarding communities and promoting sustainable development (Box 1.2).

Box 1.2. Data, collaboration and technology are key to ensure infrastructure resilience to natural disasters: Examples from Japan, Panama and the Inter-American Development Bank (IDB)

Investing in improving the availability and use of data for infrastructure resilience through collaborations in Japan

Japan is investing in data for resilient infrastructure by:

- Enhancing Satellite Observation Data Utilisation. The collaboration between the Japan Aerospace Exploration Agency (JAXA) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) aims to optimise the utilisation of satellite observation data. This includes leveraging data on global precipitation, heavy rains, droughts, hydrological circulation simulations, soil moisture levels, ground elevation, and land use maps. The objective is to furnish comprehensive and high-quality data crucial for assessing water-related disaster risks, particularly in Asian countries. By enhancing the accuracy and accessibility of such data, the collaboration aims to bolster the effectiveness of decision-making processes in disaster management.
- Climate Change Prediction and Data Integration. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) collaborates with universities and research institutes globally to conduct joint research on climate change projection using Japanese climate models. Furthermore, MEXT partners with MLIT to provide data integration and analysis services through the Data Integration and Analysis System (DIAS). This collaboration facilitates water-related risk-assessment activities in targeted countries and enhances the quality of outcomes through continuous feedback mechanisms.

Undertaking comprehensive risk assessments in the Panama Canal

In the case of the Panama Canal, a comprehensive risk analysis was conducted during the design phase, identifying over 175 potential risks associated with various natural disasters. These risks were meticulously assessed with assigned probabilities, and a Monte Carlo simulation was employed to prioritise the most critical ones necessitating mitigation measures. The outcome of this exercise enabled the anticipation and proactive management of numerous challenges inherent to the canal's construction and operation.

For instance, one notable aspect of the risk mitigation strategy was the consideration of a technical failure near the canal. To address this, the canal was engineered with a security level suitable for a seismic event of magnitude 10.0. This exemplifies a forward-thinking approach, where potential risks were not only identified but also incorporated into the design, aligning with contemporary technological standards. While such anticipatory measures may entail additional costs, they underscore a decision-making process informed by thorough risk analysis.

Leveraging advanced modeling tools and systems for water resource management by IDB

HydroBID, an initiative led by the Inter-American Development Bank (IDB), aims to address water-related challenges in Latin America and the Caribbean (LAC) through improved water management and decision-making processes. This initiative leverages advanced hydrological modeling tools and geographic information systems (GIS) to enhance water resource management across the region.

HydroBID focuses on providing decision makers with accurate and timely information regarding water availability, quality and usage, thereby enabling more effective planning and resource allocation. By utilising data-driven approaches and innovative technologies, HydroBID supports evidence-based policy making and facilitates the implementation of sustainable water management practices.

One of the key objectives of HydroBID is to strengthen the resilience of water infrastructure and services in LAC countries, particularly in the face of climate change and increasing water-related risks. Through capacity-building activities, knowledge sharing, and the development of customised tools and methodologies, HydroBID aims to empower local stakeholders to better manage water resources and mitigate the impacts of water-related disasters. Overall, HydroBID represents a comprehensive effort to improve water security, enhance environmental sustainability, and promote inclusive development in Latin America and the Caribbean by harnessing the potential of data-driven solutions and collaborative partnerships.

Source: Official information from the Ministry of Land, Infrastructure and Transport (MLIT), Japan, the Association of Caribbean States and the Inter-American Development Bank (IDB).

Adequate **financial resources** are essential for investing in resilient infrastructure projects, which often require substantial upfront costs for construction, maintenance and upgrades (OECD, 2023[16]). Without sufficient funding, infrastructure projects may lack the necessary features and measures to withstand natural disasters, leaving communities vulnerable to significant damage and disruption. To increase resilience to natural disasters such as floods, tsunamis and earthquakes, exploring innovative financing mechanisms can be an option. Among the different possibilities, one is to consider allocating a given share of tax revenues for disaster management budgets. For instance, infrastructure projects like the STAR highway in the Philippines, the Tashguzar–Baysun–Kumkurgan (TBK) railway connection in Uzbekistan and Kyushu high-speed rail line in Japan have been shown to lead to increased tax revenues post-implementation due to improved economic activity (Yoshino and Abidhadjaev, 2017[17]; Yoshino and Abidhadjaev, 2017[18]). Allocating a portion of these potential additional tax revenues to disaster management and future preparation efforts can provide a dedicated funding source for enhancing resilience against natural disasters (Azhgaliyeva, Seetha Ram and Yoshino, 2023[19]; Avellán et al., 2022[20]).

Technical expertise plays a vital role in designing, building, operating and maintaining resilient infrastructure. Engineers, architects and other technical professionals bring specialised knowledge and skills to assess risks, develop mitigation strategies, and incorporate resilience measures into infrastructure projects. Their expertise ensures that infrastructure is built to withstand the impacts of natural disasters, reducing the likelihood of damage and enhancing the overall resilience of communities.

Regulatory frameworks provide the legal and institutional reference to promote and enforce resilience-building measures in infrastructure development. Effective regulations and standards ensure that infrastructure projects comply with best practices and incorporate resilience considerations into planning, design, construction and operation (OECD, 2019[21]). Regulatory frameworks also play a crucial role in establishing accountability mechanisms, allocating responsibilities among stakeholders, and providing incentives for investing in resilient infrastructure (ITF, 2018[22]). They are also essential to ensure that data and information are effectively used to take informed actions. Mandatory inclusion of climate risk assessment in project preparation is essential. This involves evaluating the potential climate-related hazards, exposure, vulnerabilities and impacts that infrastructure assets may face over their life cycle. The regulatory framework should ensure and enforce compliance with climate resilience standards and requirements through monitoring, inspection and enforcement mechanisms. Regulatory authorities oversee the implementation of climate and natural disaster resilience measures in infrastructure projects, ensuring that developers and operators adhere to prescribed standards and guidelines. Non-compliance should result in fines as penalties, incentivising stakeholders to prioritise resilience in infrastructure development. It is important to clarify the responsibilities in terms of who needs to carry out the risk assessment and who is in charge of implementing the necessary actions based on the information gathered through the risk assessment study. Failing to clarify who has the responsibility for implementing actions might result in an underutilisation of the risk assessment analysis.

Increasing infrastructure resilience to natural disasters is a global priority. But it is even more urgent in developing countries as they suffer from severe infrastructure gaps. In particular, the following three factors are paramount for increasing infrastructure resilience to natural disasters in developing countries:

- **Increasing government anticipation and adaptation capacities.** In the face of uncertain and changing climate risks, it is important that the regulatory framework includes provisions for adapting rules when needed, while ensuring the stability and security of economic operations.
- **International partnerships** and collaboration are of critical importance to developing countries as they lag behind in terms of financing, technical and regulatory capabilities, as well as in access to data and technology.
  - Developing countries often face limited financial resources and capacity constraints, making it difficult to invest in resilient infrastructure projects. International partnerships can mobilise funding from donor countries, international financial institutions, and private sector investors, supplementing domestic resources and supporting the implementation of infrastructure projects that enhance resilience.
  - International partnerships can facilitate the transfer of technical expertise and knowledge in a wide range of areas, including engineering, risk assessment, disaster management and regulatory frameworks. By leveraging the technical knowledge and experience of international partners, developing countries can enhance their capacity to plan, design and implement resilient infrastructure projects that are tailored to local needs and conditions.
  - Collaborative initiatives between governments, international organisations and other stakeholders can facilitate the exchange of best practices, standards and guidelines for incorporating resilience considerations into regulatory frameworks and policies. Additionally, capacity-building programmes supported by international partnerships help strengthen the institutional capacities of developing countries to develop, enforce and monitor regulatory frameworks related to infrastructure resilience.
- **Multilateral development banks (MDBs), Development Finance Institutions (DFIs) and National Development Banks (NDBs)** are key players in increasing developing countries' capacities to plan, build and operate infrastructure resilient to natural disasters. Development banks provide a wide array of services beyond direct financing, including de-risking and risk assessment tools (Box 1.3).

Box 1.3. Development banks are fundamental players in enabling infrastructure resilience to natural disasters

- **Financing**, through a variety of instruments, including loans, grants and guarantees. They often offer concessional terms and flexible financing options to support projects that incorporate climate resilience measures, such as climate risk assessments, adaptation strategies and resilience-enhancing technologies. Additionally, development banks can leverage their financial resources to attract co-financing from other sources, including the private sector and international climate finance mechanisms.
- **Technical assistance and capacity building.** Development banks offer technical assistance and capacity building support to enhance the readiness and implementation of climate resilient infrastructure projects. Also, international and national development banks actively structure and prepare infrastructure projects, which includes providing technical expertise in climate risk assessments, engineering design, project management, and monitoring and evaluation. Development banks also facilitate knowledge exchange and best-practice sharing among

countries facing similar climate challenges, helping to build local capacity and expertise in climate resilient infrastructure development.

- **Policy and regulatory support.** Development banks play a crucial role in shaping policy and regulatory frameworks that promote climate resilient infrastructure development. They work closely with governments to strengthen regulatory standards, codes and guidelines related to climate resilience in infrastructure planning, design and construction. Development banks also advocate for policy reforms that incentivise investment in climate resilient infrastructure and integrate climate risk considerations into national development strategies and sectoral plans.
- **Project screening and due diligence.** Development banks conduct rigorous screening and due diligence processes to ensure that the infrastructure projects they could finance are climate resilient and environmentally sustainable. This includes assessing climate risks and vulnerabilities, evaluating the resilience of proposed infrastructure designs and technologies, and considering the long-term climate impacts and adaptation strategies. Development banks also incorporate climate resilience criteria into project appraisal and approval processes, guiding investment decisions towards projects that enhance resilience and reduce vulnerability to climate change.
- **Knowledge sharing and innovation.** Development banks facilitate knowledge sharing and innovation in climate resilient infrastructure by supporting research, pilot projects and knowledge exchange platforms. They invest in research and development of innovative technologies and approaches that enhance climate resilience in infrastructure, such as green infrastructure, nature-based solutions, and resilient urban planning. Development banks also promote learning and capacity building through workshops, seminars and conferences, fostering a culture of innovation and continuous improvement in climate resilient infrastructure development.

Source: OECD (2024[15]), *Infrastructure for a Climate-Resilient Future*.

Conclusions

Ensuring that infrastructure is planned, built and operated in a way that is resilient to natural disasters is a global priority due to the rise in frequency, intensity and impact of natural hazards and extreme weather events. It fosters development by:

- Contributing to economic stability, by reducing the risk of infrastructure damage and disruptions caused by extreme weather events. This stability is crucial for attracting long-term investment and fostering sustained economic growth. Investors are more likely to commit resources to countries with resilient infrastructure that can withstand climate shocks, ensuring the continuity of operations and returns on investment.
- Safeguarding critical assets and services, such as transportation networks, energy systems, water supply and telecommunications. For example, reinforcing coastal infrastructure, such as seawalls and flood barriers, protects ports and transportation routes from sea-level rise and storm surges, ensuring the uninterrupted flow of goods and services.
- Minimising life cycle costs by reducing the need for frequent repairs and emergency maintenance due to climate-related damages. By investing upfront in resilient design and construction techniques, developing countries can avoid costly retrofitting and reconstruction efforts.
- Reducing the risk premium. Insurance companies and risk assessors increasingly consider the resilience of infrastructure assets when underwriting policies and assessing risk exposure. By

investing in climate-resilient infrastructure, developing countries can reduce insurance premiums and financial liabilities associated with climate-related risks.

- Fostering innovation and technological development. Prioritising resilience to climate change in infrastructure drives the development of new materials, design approaches and construction techniques that enhance resilience. This fosters a culture of innovation and entrepreneurship, creating opportunities for the growth of local industries and the adoption of cutting-edge technologies in infrastructure development. By preserving ecosystems as wetlands, forests and natural waterways and by integrating nature-based solutions into infrastructure design, such as green roofs, permeable pavements and natural drainage systems, it fosters bioeconomy development and generation of sustainable economic value from natural assets.
- Increasing integration and partnerships with global markets. Adhering to international standards, regulations and agreements aimed at addressing climate change and promoting sustainable development enhances credibility and reputation on the global stage, facilitating access to international financing, partnerships and co-operation. It is essential that developing countries participate in the definition of global climate resilience standards for infrastructure. These are norms, codes and guidelines that govern the design, construction and operation of infrastructure projects. They define the minimum requirements for infrastructure resilience, including considerations such as climate risk assessments, adaptive design strategies, durability and maintenance requirements.
- Increasing social equity and inclusion. Vulnerable and marginalised communities often bear the brunt of disasters' impacts and are disproportionately affected by inadequate infrastructure, hampering their economic inclusion prospects, therefore perpetuating poverty cycles. Infrastructure projects must be designed and implemented in a way that ensures resilience to natural disasters and at the same time promotes social equity, ensures access to essential services for all, and empowers local communities to actively participate in decision-making processes. It is important to take into account gender perspectives in this respect (OECD, 2023[23]).

To ensure resilience to natural disasters, national and local governments need to increase their prevention, reaction and re-building capacities through effective collaboration, smart use of data and deployment of new technologies, enabled by access to finance and technical expertise and in the presence of conducive regulatory frameworks that incentivise taking into account resilience to natural disasters in all project phases and that clearly establish responsibilities and accountability mechanisms.

For developing countries, international partnerships and development banks are key partners in achieving resilience to natural disasters in infrastructure projects. Both should be scaled up to be able to rise to the challenge of closing infrastructure gaps to match development aspirations of emerging and developing economies and to do it in a way that is future-proof and resilient to climate change and natural disasters. Chapter 2 presents seven good practices to make infrastructure resilient to natural disasters and Chapter 3 discusses seven concrete infrastructure projects in prevention, reaction and rebuilding efforts.

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2 Global good practices for infrastructure resilience to natural disasters

Ensuring infrastructure resilience to natural disasters is highly context-specific, but some universal principles apply. Based on global good practices, this chapter presents seven guiding principles for enhancing infrastructure resilience to natural disasters. It discusses why and how to: i) Adopt a life cycle approach, factoring in resilience throughout the entire lifespan of projects from planning and design to operation and maintenance; ii) Align interests through effective collaboration among stakeholders to ensure collective action towards resilience goals; iii) Conduct comprehensive risk assessments to identify vulnerabilities and develop robust mitigation strategies; iv) Measure impacts to understand the consequences of natural disasters and guide informed decision making; v) Invest in capacity building and knowledge management to empower individuals and organisations with the skills and information needed to plan, implement and operate resilient infrastructure; vi) Carry out strategic preventive maintenance; and vii) Deploy cutting-edge technology and fostering innovation in design to enhance infrastructure resilience and adaptability to changing environmental conditions.

Introduction

Infrastructure development in emerging and developing economies should ensure higher levels of economic efficiency and local socio-economic empowerment to achieve national development visions. It should aim to reduce poverty, income and gender inequality, and social exclusion, while improving labour productivity and competitiveness as well as ensuring environmental and social safeguards (OECD/CAF/ECLAC, 2013[1]; Ministry of Foreign Affairs Japan, 2016[2]). To this end, G20 members formulated the Roadmap to Infrastructure as an Asset Class under Argentina's 2018 presidency, and endorsed the G20 Principles for Quality Infrastructure Investment under Japan's 2019 presidency (G20, 2019[3]; OECD, 2020[4]; OECD, 2021[5]) (Box 2.1).

Box 2.1. The G20 Principles on Quality Infrastructure

Quality infrastructure has been widely recognised as key to achieving sustainable, resilient and inclusive growth. In the 2030 Agenda for Sustainable Development, SDG no. 9 on Industry, Innovation and Infrastructure calls for the development of "quality, reliable, sustainable and resilient infrastructure, including regional and cross-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all". Quality infrastructure contributes to the achievement of other goals envisaged in the 2030 Agenda for Sustainable Development. Improved infrastructure services can result in lower inequalities and greater inclusion (SDGs no. 5 and 10), improved well-being (SDG no. 3), increased access to clean water and sanitation (SDG no. 6) as well as to jobs and education (SDGs no. 4 and 8), and more resilient and sustainable cities (SDG no. 11). Moreover, quality infrastructure can contribute to poverty reduction (SDG no. 1) while also meeting environmental goals (SDGs no. 13, 14 and 15).

Various global fora in addition to the G20 have recently recognised the importance of, and contributed to the definition of, quality infrastructure. In 2016, the G7 summit in Ise-Shima, Japan endorsed the *Principles for Promoting Quality Infrastructure Investment.* The significance of investing in quality infrastructure with open, fair access and responsible financing was also confirmed at the G7 Charlevoix Summit in Canada in June 2018. The G7 under the Japanese Presidency also reinforced the importance of quality infrastructure in the G7 Hiroshima Leaders' Communiqué in 2023 (G7, 2023[6]).

The G20 Principles for Quality Infrastructure Investment are to:

1. Maximise the positive impact of infrastructure to achieve sustainable growth and development
2. Raise economic efficiency in view of life-cycle cost
3. Integrate environmental considerations in infrastructure investments
4. Build resilience against natural disasters and other risks
5. Integrate social considerations in infrastructure investments
6. Strengthen infrastructure governance

Source: (UNDP, 2018[7]), (G7, 2018[8]) and (G7, 2016[9]).

Ensuring infrastructure resilience to natural disasters is highly context-specific. However, some general principles apply and when implemented they can increase the effectiveness and the efficiency of prevention, reaction and re-building efforts.

This chapter presents seven guiding principles for making infrastructure resilient to natural disasters. These principles are based on the case studies discussed in detail in Chapter 3 of this report, and on the expert and peer-review process implemented in the framework of the preparatory works of the 2024 edition of the *Compendium of Good Practices on Quality Infrastructure*. The seven principles are not intended to be exhaustive, and they are all of equal importance and interrelated.

Each guiding principle is presented following a similar structure:

- the rationale and the associated benefits and/or costs of non-aligned action
- the enabling conditions for implementation, associated with a clarification of the specific challenges and needs in the specific case of developing countries
- good practices for implementation.

Each section concludes with a short box referring to how the principle has been implemented in a specific case. Although each box associates one case study with one of the guiding principles, all the case studies can be associated with most of the identified principles. The association of a case study with a guiding principle has been made based on the most prominent feature of each case study.

The seven guiding principles are:

- adopting a life cycle approach
- ensuring interests' alignment through effective collaboration
- conducting risk assessment
- measuring impacts
- investing in capacity building and knowledge management
- carrying out strategic preventive maintenance
- deploying cutting-edge technology and fostering new design and innovation.

Adopting a life cycle approach

The life cycle approach in infrastructure refers to a comprehensive perspective that considers from the outset that each infrastructure project encompasses multiple phases, from planning and design to construction, operation, maintenance, and eventual decommissioning or renovation.

This approach recognises that infrastructure assets have long life spans and undergo various phases throughout their life cycle, each of which presents unique challenges and opportunities. The life cycle approach matters because it enables stakeholders to make informed decisions that optimise the performance, resilience and sustainability of infrastructure assets over their entire lifespan.

This approach is essential for effective infrastructure planning – which includes project preparation and design – and it is a precondition to ensure infrastructure's resilience to natural disasters. It allows identifying from the outset the interdependencies between the different phases and to effectively plan and invest by minimising costs and maximising efficiency. A decision taken during the construction phase can lead to changes in the operation and maintenance phases. For example, roads constructed with durable materials to withstand stress changes, might require less frequent but more comprehensive maintenance. Roads in flood-prone areas can incorporate adapted design features such as single-lane raised roads (another decision and action implemented during the construction phase) that will impact reaction capacities and change operations during emergency responses. To ensure that infrastructure is planned, designed, constructed, operated, maintained and renovated or repurposed in a way that makes it resilient to natural disasters, the life cycle approach matters because it enables:

- **Integrated risk management.** By considering the entire life cycle of infrastructure, planners can integrate risk management strategies at each stage, from design to maintenance. This includes identifying potential hazards, assessing vulnerabilities and implementing appropriate mitigation measures to prevent or minimise the impact of natural disasters.

- **Resilience enhancement.** Infrastructure designed with a life cycle approach can incorporate resilience features at the outset and in all phases to enhance its ability to withstand natural disasters. For example, incorporating robust materials, appropriate construction techniques, and disaster-resistant designs during the planning phase can significantly reduce the vulnerability of infrastructure to various hazards.
- **Adaptive capacity.** Planning with a life cycle approach allows for the integration of adaptive measures that enable infrastructure to respond effectively to changing environmental conditions and evolving disaster risks over time. This flexibility ensures that infrastructure remains resilient and adaptable in the face of emerging challenges.
- **Cost savings and sustainable investment.** Taking a life cycle approach in planning infrastructure projects allows for more efficient allocation of resources. It enables the identification of cost-effective solutions that provide optimal performance and functionality throughout the asset's lifespan. Investments made upfront in resilience measures, such as hazard-resistant construction and proactive maintenance, result in long-term cost savings by reducing the need for expensive repairs and reconstruction in the aftermath of natural disasters and by ensuring operations or minimising disruptions in the aftermath of a natural hazard.

It is of utmost importance to carry out a life-cycle cost analysis in the planning phase. Implementing a life cycle approach necessitates conducting comprehensive life-cycle cost analysis during the project planning phase. This analysis should encompass not only initial construction expenses but also ongoing maintenance, operation and end-of-life costs to determine the most cost-effective solutions. To ensure that the life-cycle cost analysis in the planning phase is carried out, targeted policies and, in certain cases, regulations, are needed. In particular, these policies and regulations might include:

- Incentives, in the form of direct and indirect financial support to projects that embrace a life cycle approach. These incentives should direct developers to prioritise sustainability and long-term benefits over short-term gains.
- Environmental impact assessments to evaluate the potential environmental consequences of infrastructure projects throughout their life cycle. This includes assessing resource usage, emissions, and potential habitat disruptions.
- Development and implementation of systems to collect, manage and share life-cycle data. Access to comprehensive data facilitates informed decision making and future improvements.

Developing countries encounter more pronounced challenges than advanced economies in implementing a life cycle approach in infrastructure planning, due to several factors, including:

- **Limited resources.** Developing countries often have constrained financial, technical and human resources, making it difficult to conduct comprehensive life-cycle cost analyses or invest in long-term infrastructure solutions.
- **Capacity constraints.** Developing countries may lack the technical expertise and institutional capacity required to perform robust life-cycle assessments, collect relevant data, and make informed decisions throughout the infrastructure life cycle.
- **Short-term focus.** Developing countries may be under pressure to prioritise short-term economic considerations over long-term sustainability and resilience, leading to infrastructure projects that prioritise initial competitive construction costs rather than considering long-term life-cycle costs.
- **Regulatory and institutional constraints.** In several cases, developing countries lack the necessary regulatory and institutional framework for implementing a life cycle approach and integrating resilience at the outset in the infrastructure planning phase.

In addition to a mindset shift in infrastructure planning in developing countries towards infrastructure as a strategic asset rather than a cash-cow, international partnerships emerge as pivotal to overcome these challenges and support developing countries' uptake of a life cycle approach in infrastructure to ensure resilience to natural disasters. In particular, international partnerships can contribute to:

- Increase public awareness and stakeholder engagement. Raising awareness among policy makers, stakeholders and the public about the importance of a life cycle approach in infrastructure planning is essential to ensure buy-in and support for long-term infrastructure investments.
- Update the regulatory frameworks, and national and local policies to mandate the adoption of a life cycle approach in infrastructure planning and development, taking into account each country's specificities, and historical and geographical context.
- Invest in capacity building initiatives to enhance technical skills and institutional capacity in life-cycle analysis, data collection and decision-making processes related to infrastructure planning.
- Foster knowledge sharing and peer dialogue. Partnerships and collaborations with international organisations, development agencies and advanced countries to share best practices, knowledge, and experiences in implementing life cycle approaches in infrastructure planning contribute to foster advancements in developing countries and enable the co-development of new practices in the current fast evolving global landscape.
- Explore innovative financing mechanisms, such as public-private partnerships, green bonds or impact investment funds, to mobilise resources for sustainable infrastructure projects with a focus on life-cycle considerations (ITF, 2018[10]).

By addressing these challenges and implementing appropriate strategies thanks to supportive international partnerships, developing countries can enhance their capacity to adopt a life cycle approach in infrastructure planning and contribute to building more sustainable and resilient infrastructure systems.

Box 2.2. India has adopted a life cycle approach to infrastructure which resulted in increased resilience to natural disasters in its highway projects

India has implemented measures to ensure its highway projects are resilient to natural disasters at all stages of the process, from planning and design through construction, operation, maintenance, to end-of-life. In the planning phase, a risk assessment has been conducted for all the lifespan of assets. During the planning stage, India has conducted detailed studies of an area's topology, geography and hydrology to avoid higher-risk areas or ensure that mitigation systems can effectively match the risks. Additionally, disaster exposure mapping (e.g. earthquakes) has been utilised to determine which areas require specific levels of investment in different disaster mitigation features.

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

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

Source: Case study "Increasing connectivity and preserving the environment through sustainable highways in India" in Chapter 3 – Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD.

Ensuring interests' alignment through effective collaboration

Effective collaboration among multiple stakeholders is essential to prevent, react and rebuild infrastructure. Effective collaboration refers to domestic and international efforts. Effective collaboration results in faster, more equitable and improved actions deriving from interests' alignment (OECD, 2024[11]). It ultimately helps to foster financial risk-sharing among various public and private entities across sectors and countries affected by the impacts of natural disasters and it enhances project efficiency by facilitating knowledge exchange among these entities. It also contributes to project equity by allowing to consider everybody's perspective. By engaging with a diverse range of stakeholders, collaboration brings together varying perspectives, expertise and resources, leading to a more comprehensive understanding of challenges and a more effective response. Collaboration contributes to:

- **Increasing government, civil society, and private sector awareness and know-how.** Effective collaboration builds the knowledge base for government actions and public-private partnerships and increases the collective response capacity to prevent and mitigate the impacts of natural disasters. Infrastructure systems are interconnected, and disruptions in one sector can have cascading effects on others. Collaborative efforts ensure a holistic approach that considers the interdependencies and interactions between different systems, thereby reducing vulnerability and enhancing overall resilience.
- **Cost and implementation sharing.** Effective collaboration allows for efficient division of labour in implementation as well as cost-sharing and funding pooling across multiple actors, ultimately resulting in increased cost effectiveness. Collaboration also facilitates a better distribution of risks, thereby reducing capital costs.
- **Leveraging diverse expertise.** By pooling together diverse skill sets, knowledge and preferences, collaboration enhances the effectiveness of disaster response and resilience-building efforts. Various stakeholders, including governments, private sector entities, community groups and non-governmental organisations, offer unique insights into local needs and priorities. Collaborating with these stakeholders ensures that resilience strategies are inclusive and address social equity issues, as well as the needs of the concerned communities. Collaboration also facilitates more comprehensive scenario planning and risk management strategies, aiding in the identification of potential vulnerabilities and areas requiring greater attention to enhance infrastructure resilience.

Collaboration yields numerous benefits in terms of cost reduction, increased financing and social acceptance, thereby averting delays and cost overruns. Resilient infrastructure often necessitates substantial financial investments, technical expertise and operational capabilities. Collaboration enables the pooling of resources, sharing of best practices, and tapping into the expertise of multiple parties, leading to more efficient and cost-effective solutions.

To align interests and achieve effective collaboration for infrastructure resilient to natural disasters, the following actions are of pivotal importance. In particular, it is important to act in the prevention phase, as these practices need to be already in place and operational before the reaction and rebuilding phase, as they will be crucial for effective response to natural disasters:

- **Developing a common vision focused on long-term sustainability.** Work together to develop a shared vision for resilient infrastructure that aligns with the goals and priorities of all stakeholders. This common vision can serve as a guiding framework for collaborative efforts and decision making. Emphasise the importance of long-term thinking and investment in resilience over short-term gains. Prioritise strategies and initiatives that promote the sustainability and effectiveness of resilient infrastructure in the face of evolving challenges.
- **Establishing clear communication channels.** Ensure open and transparent communication among stakeholders to foster trust and understanding. Regular updates, meetings and feedback mechanisms can help maintain clear communication channels.

- **Building trust among stakeholders.** Foster trust through transparent decision-making processes, equitable representation and mutual respect for diverse perspectives. Building relationships based on trust can help overcome competing interests and conflicts.
- **Establishing clear governance mechanisms.** Define clear decision-making structures and governance mechanisms that ensure equitable participation and representation of all stakeholders. It is important to establish fair rules for funding allocation and knowledge-sharing can promote collaboration and mitigate governance challenges. It is also necessary to define clear institutional responsibilities and inter-institutional collaboration mechanisms, as well as establishing mechanisms for co-ordination between the national and local government levels (OECD, 2024[12]; SNG-WOFI, 2022[13]).
- **Establishing multi-stakeholder partnerships.** Developing countries can create multi-stakeholder partnerships involving government agencies, local communities, private sector entities, non-governmental organisations (NGOs) and international organisations. These partnerships enable diverse stakeholders to contribute their expertise, resources and perspectives to resilience-building efforts.
- **Incentivising collaboration through policy measures.** Governments can incentivise collaboration for resilience building through policy measures such as tax incentives, grants and subsidies for collaborative projects and initiatives. Policy frameworks that encourage public-private partnerships (PPPs) and cross-sectoral collaboration can facilitate the pooling of resources and expertise for infrastructure resilience.
- **Engaging local communities.** Engaging local communities in resilience-building efforts is crucial for ensuring that infrastructure projects meet the needs and priorities of the people they serve. Community participation in decision-making processes, project planning and implementation can enhance the relevance, effectiveness and sustainability of resilience initiatives.

Four issues challenge collaboration in resilient infrastructure projects, and are of particular relevance in the case of developing countries:

- **Competing interests.** Different stakeholders may have divergent interests, priorities and objectives regarding infrastructure development, leading to conflicts and difficulties in finding common ground for collaboration.
- **Resource constraints.** Building resilient infrastructure often requires substantial financial resources, technical expertise and data. Limited resources among collaborating parties can hinder the implementation of collaborative initiatives.
- **Governance and institutional challenges.** In multi-stakeholder collaborations, decision-making structures and governance mechanisms may not be well-defined or agreed upon. This ambiguity can slow down the decision-making process and create uncertainties.
- **Short-term thinking.** Resilient infrastructure requires a long-term perspective, but some stakeholders might prioritise short-term gains over investing in resilience, potentially overlooking the importance of long-term sustainability and effectiveness.

To address these gaps, international partnerships are essential in particular for:

- **Promoting information sharing and knowledge exchange.** Governments and organisations in developing countries can facilitate information sharing and knowledge exchange platforms focused on resilience building. These platforms can include workshops, conferences, webinars and online portals where stakeholders can share best practices, lessons learned, and innovative solutions for infrastructure resilience.
- **Enhancing capacity building.** Capacity building programmes can be implemented to enhance the technical skills and knowledge of stakeholders involved in infrastructure development and disaster risk management. This includes training programmes, workshops and educational

initiatives aimed at improving understanding of resilience concepts, risk assessment methodologies and effective mitigation strategies.

- **Leveraging international support and funding.** Developing countries can leverage international support and funding mechanisms provided by donor agencies, multilateral development banks, and other international organisations. Collaborative projects funded by international donors can support the development of resilient infrastructure and provide opportunities for knowledge transfer and technology exchange.
- **Promoting South-South co-operation.** Developing countries can benefit from South-South co-operation initiatives, where countries with similar development challenges share experiences, expertise and resources to support each other's resilience-building efforts. South-South co-operation can facilitate the exchange of knowledge, technologies and innovative solutions tailored to the specific contexts of developing countries.

In conclusion, collaboration in building resilient infrastructure is crucial because no single entity or sector can effectively address the complexities of resilience alone. Through collaboration, stakeholders can leverage their strengths, minimise duplication of efforts, and establish a more robust and adaptive infrastructure system capable of withstanding and recovering from various shocks and stresses.

Box 2.3. The Fargo-Moorhead Flood Diversion Project in the United States achieved increased resilience to natural disasters through effective collaboration

Multi-stakeholder co-ordination. Efforts to address the flooding challenges in the Fargo-Moorhead area began with local stakeholders taking action. This led to the creation of an authority aimed at raising funds for constructing a 30-mile flood diversion channel. A significant milestone was reached when the US Army Corps of Engineers became involved, marking the point at which both local and federal governments became actively engaged. Eventually, the project expanded to involve the state government and local stakeholders from Minnesota, who were also affected by similar disruptions. Over time, the project garnered support from over 50 organisations across the public and private sectors, including 20 utility companies and 30 federal, state and local agencies. The co-ordination efforts involved navigating through 14 pieces of legislation, obtaining 200 permits (with over 2 000 conditions to be tracked), and establishing 70 memorandums of understanding, representing a massive co-ordination effort among government entities.

Funding sources. The Fargo-Moorhead Flood Diversion Project secured significant funding from various sources to support its implementation. A substantial amount of USD 750 million (United States dollars) was allocated by the federal government through a Project Partnership Agreement with the US Army Corps of Engineers, with USD 437 million of this funding provided by the Infrastructure Investment and Jobs Act of January 2022. Additionally, the project received state grants, including USD 850 million from North Dakota and USD 86 million from Minnesota, reflecting cross-border collaboration efforts. Local revenues also played a crucial role, with approximately USD 1.514 billion generated, primarily through sales tax. Furthermore, financing mechanisms such as a low-interest loan of USD 569 million from the US Environmental Protection Agency and USD 55 million in state Revolving Fund loans issued by the North Dakota Public Finance Agency were utilised. The project also benefited from USD 280 million in loans provided by the US Department of Transportation's Private Activity Bonds (PABS), contributing to its overall financing structure.

Source: Case study "United States: Fargo-Moorhead Flood Diversion Project" in Chapter 3 – Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD.

Conducting risk assessment

Risk and impact assessment in infrastructure refers to the systematic process of evaluating potential risks, vulnerabilities and consequences associated with natural disasters and other disruptive events on infrastructure systems. This assessment aims to identify and understand the likelihood and severity of various hazards, such as floods, earthquakes, hurricanes and climate-related events, as well as human-induced risks like cyberattacks or terrorist threats, on infrastructure assets. The assessment considers multiple factors, including the vulnerability and exposure of infrastructure assets, the capacity of systems to withstand or adapt to disruptions, hazard characteristics and environmental conditions. It involves analysing historical data, hazard scenarios, and predictive models to assess the potential impacts on human life, economic activities, environmental assets and social well-being.

Through risk and impact assessment, decision makers can make informed choices about resource allocation, prioritise efforts, and develop proactive strategies to enhance the resilience of infrastructure systems (OECD, 2018[14]). This includes implementing preventive measures, improving emergency response and recovery plans, and integrating resilience considerations into infrastructure planning, design, construction, operation and maintenance processes. Overall, risk and impact assessment play a crucial role in building resilient infrastructure that can withstand and recover from various challenges, contributing to the sustainable development and well-being of communities.

Resilient infrastructure refers to the ability of a system or structure to withstand and adapt to changing conditions, shocks and stresses while continuing to provide essential services to the community. Furthermore, resilient infrastructure not only shields communities and the economy from disruptions caused by natural disasters but also fosters sustainable development in a changing world. By incorporating resilience into infrastructure planning and design, communities can better adapt to environmental changes and mitigate the impacts of disasters, thereby promoting long-term sustainability.

Risk assessment plays a fundamental role in this process by identifying:

- the expected probability of different natural disasters and their potential impact
- risk interdependence between sectors, such as an increased vulnerability to flood damage which creates risks to be considered in road and electrical distribution infrastructure
- the potential for simultaneous occurrence of natural disasters across regions.

Moreover, the assessment enables the implementation of prevention and mitigation activities to reduce the likelihood and severity of disasters. It also facilitates the development and implementation of appropriate preparedness measures, ensuring that communities are adequately equipped to respond effectively to disasters when they occur. Overall, a comprehensive risk assessment is a cornerstone of proactive disaster risk management and plays a vital role in enhancing infrastructure resilience and promoting sustainable development. Risk assessment significantly enhances prevention and preparedness capacities in case of natural disasters, and provides important information in the reaction and rebuilding phase by:

- **Providing information to assess vulnerabilities.** Risk assessment helps identify vulnerabilities within the infrastructure system, such as weak points, exposure and vulnerability to hazards, and potential points of failure. This understanding is essential for implementing targeted resilience measures to address these vulnerabilities effectively. By analysing historical data, hazard characteristics and environmental factors, decision makers can anticipate and understand the nature and magnitude of potential threats.
- **Enabling risk-informed decision making and increasing adaptive capacities.** Risk assessment provides decision makers with the information needed to make informed decisions about infrastructure resilience. By understanding the potential risks and vulnerabilities, decision makers can develop and implement resilience strategies that enhance infrastructure's ability to

withstand natural disasters and minimise their impact on communities and economies. Risk assessment facilitates adaptive planning by identifying evolving risks and vulnerabilities over time. As climate change and other factors contribute to changing risk profiles, ongoing risk assessment allows for adjustments to resilience strategies and measures to ensure infrastructure remains resilient in the face of new challenges.

- **Prioritising resilience measures and resource allocation.** By assessing the likelihood and potential impact of different natural disasters, risk assessment enables decision makers to prioritise resilience measures. High-risk areas or infrastructure components can receive more attention and resources to strengthen their resilience, leading to a more efficient allocation of resources. Risk assessment provides valuable information for allocating resources effectively. It allows decision makers to identify areas with the highest risk and allocate resources accordingly to mitigate those risks. This ensures that limited resources are directed towards the most critical areas to maximise their impact on infrastructure resilience. Understanding the magnitude of a disaster enables prioritisation of funding toward areas facing the greatest risk. While the long-term goal is to equip all vulnerable areas with adequate resilience measures, in the short term, it's essential to allocate funds where they can have the most immediate impact. This targeted approach is crucial for swiftly minimising the disaster's economic repercussions.
- **Enabling targeted prevention measures.** With a comprehensive understanding of the risks, preventive measures can be targeted and tailored to specific vulnerabilities. This includes infrastructure improvements, land-use planning, and the implementation of building codes and regulations designed to mitigate the impact of natural disasters.
- **Increasing community awareness and engagement.** Risk assessment fosters community awareness and engagement in disaster preparedness efforts. By communicating the findings of risk assessments to the public, communities can better understand their vulnerabilities and take proactive measures to mitigate risks, such as securing property, creating emergency kits, and participating in community resilience-building initiatives.

The risk assessment process involves three key steps:

- **Identifying the hazards that the infrastructure may face is essential.** These hazards encompass various natural events such as earthquakes, floods, hurricanes and climate-related phenomena, as well as human-induced risks like cyberattacks or terrorist threats. Once the hazards are identified, efforts and resources are focused on addressing them.
- **Estimating the likelihood or probability of each hazard is crucial.** Understanding the type of disaster faced, whether it's flooding, earthquakes, wildfires or others, guides the selection of appropriate resilience measures. For example, while drainage culverts are effective for managing flooding, they provide little protection against earthquakes. Additionally, considering the expected magnitude and physical characteristics of the disaster is vital to ensure that the chosen measures are suitable and cost-effective.
- **Measuring the potential impacts of the identified hazards to evaluate the costs and benefits of various activities.** This assessment includes evaluating the consequences on human life, economic activities, environmental assets and social well-being, that stem from the likelihood of a hazard to occur, as well as exposure and vulnerability to it. By combining information about potential impacts and likelihood, decision makers can prioritise risks and allocate resources accordingly. High-risk areas can receive more attention and resources during the planning and implementation of resilient infrastructure projects. These measures may include strengthening the infrastructure, improving maintenance practices, incorporating redundancy, and exploring nature-based solutions.

To ensure the effective assessment of infrastructure resilience, specific conditions must be established to ensure that the assessment process is thorough, accurate and useful for decision making:

- **Data collection.** A reliable and comprehensive dataset is essential for a robust risk assessment (OECD, forthcoming[15]). This should include historical data on past hazards, infrastructure performance, and their impacts. Additionally, real-time data collection systems can provide up-to-date information to assess current vulnerabilities.
- **Multidisciplinary skills.** Risk assessment for infrastructure resilience should involve experts from various disciplines, including engineers, geologists, climatologists, social scientists and economists. This multidisciplinary approach ensures a comprehensive understanding of the risks and potential impacts.
- **Stakeholder involvement.** Engaging stakeholders such as local communities, government agencies, private sector partners and non-governmental organisations is crucial. Their input provides valuable insights into specific vulnerabilities and priorities, enhancing the overall effectiveness of the assessment.
- **Consideration of climate change.** Given the increasing frequency and intensity of climate-related hazards, risk assessment should take into account climate change projections to understand future risks and plan for adaptation.
- **A targeted regulatory framework** that incentivises and mandates risk assessment may encourage infrastructure developers and operators to consider resilience in their planning and operations.
- **Risk awareness education.** Education and awareness initiatives among stakeholders about the importance of risk assessment and the benefits of investing in resilient infrastructure are essential components. However, it is crucial to note that risk assessment is not a one-time process; it should be regularly revisited and updated as conditions change, new information becomes available, or when the infrastructure undergoes modifications.

Developing countries face limited financial and institutional capacities for risk assessment, nevertheless they can and should establish an effective risk assessment system, in particular through the following actions:

- **Prioritising risk assessment.** Despite limited resources, governments should prioritise risk assessment as a foundational step in disaster risk management. By allocating available funds strategically to prioritise risk assessment for critical infrastructure and high-risk areas, countries can lay the groundwork for informed decision making. Multilateral development banks (MDBs) and development finance institutions (DFIs) can play a pivotal role in this respect.
- **Utilising existing data.** While developing countries may have limited resources for data collection, they can leverage existing data sources such as satellite imagery, remote sensing technologies, historical records and community knowledge. Governments can collaborate with international organisations, research institutions and NGOs to access and analyse available data to identify hazard-prone areas and assess infrastructure vulnerabilities.
- **Building institutional capacity.** Developing countries need to strengthen their institutional capacity by training local experts, establishing partnerships with academic institutions, and collaborating with international organisations and international partners to develop technical expertise in risk assessment methodologies. Governments can also prioritise capacity-building initiatives to enhance the skills of government officials and stakeholders involved in disaster risk management.
- **Promoting stakeholder engagement.** Engaging stakeholders, including local communities, government agencies, private sector partners, and non-governmental organisations, is essential for effective risk assessment. Despite the challenges to engage stakeholders in contexts of high poverty and inequality, developing countries need to foster collaboration and information sharing

among stakeholders to gather diverse perspectives, local knowledge and expertise, contributing to a more comprehensive risk assessment process.

- **Utilising available risk assessment tools.** Developing countries can leverage existing risk assessment tools and methodologies developed by international organisations such as the United Nations Office for Disaster Risk Reduction (UNDRR), World Bank, and other multilateral agencies. These tools provide standardised frameworks and methodologies for assessing infrastructure vulnerabilities and prioritising risk management interventions.
- **Seek international support.** Developing countries can seek international support and technical assistance from donor agencies, development partners and regional organisations to establish and strengthen risk assessment systems. International support can provide funding, technical expertise and capacity-building opportunities to enhance the effectiveness of risk assessment efforts in developing countries (Box 2.5).

Overall, risk assessment serves as a cornerstone for building prevention and preparedness capacities, enabling authorities and communities to proactively mitigate the impact of natural disasters and enhance their resilience to future events.

Box 2.4. Risk and impact assessments as success factors in the restoration of the Dique Canal in Colombia and in the MRT (Mass Rapid Transport) in Jakarta, Indonesia

The restoration of the Dique Canal represents a multifaceted endeavour aimed at revitalising a historically significant waterway while addressing contemporary challenges, restoring a degraded ecosystem and preventing flooding. By leveraging innovative solutions and collaborative partnerships, the restoration project has the potential to deliver lasting benefits in terms of transportation efficiency, environmental conservation and regional development.

The comprehensive risk and impact assessment and the understanding of the negative impacts of climate change and natural disasters, notably the significant flood in 2010/11 of the area surrounding the Dique Canal, provided a solid foundation for the project. A multitude of data and information from various sources have been meticulously analysed in this broad assessment, contributing to a nuanced understanding of the challenges and opportunities associated with the project.

In the MRT (Mass Rapid Transport) project in Jakarta, Indonesia, continuous risk and impact assessments were conducted to identify potential major disasters, such as assessments of the potential increase in flood levels (heavy rainfall due to climate change, sea level rise, land subsidence), earthquakes, fire, terrorism and power failure. Recent trends and long-term predictions were analysed to inform decision making for improvement in disaster-resilient design. Precise data necessary for assessment was collaboratively obtained from relevant institutions, and digital technologies were used for the risk and impact assessment analysis.

Effective co-ordination with the Meteorology, Climatology, and Geophysics Agency (BMKG) facilitated access to essential climate, meteorological, hydrological and seismic data. The installation of flood panels was based on hydrological and disaster studies against predicted flood levels under a 200-year rainfall return period. Updates in the hydrological study were based on additional considerations of heavy rainfalls due to climate change, sea level rises and land subsidence, conducted and co-ordinated with the Provincial Government of the Special Capital Region of Jakarta and other relevant organisations.

Source: Case study "Restoring a degraded ecosystem and preventing flooding in the Dique Canal in Colombia" in Chapter 3 – Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD.

Box 2.5. International partnerships for enhancing risk assessment capacities in developing countries

The importance of international co-operation and collaboration in supporting risk assessment and resilience-building efforts to address the growing challenges posed by natural disasters cannot be underestimated. By working together, countries can enhance their capacities to assess, manage and reduce disaster risks, ultimately building more resilient communities and infrastructure. Below are some examples of international organisations active in the field:

United Nations Office for Disaster Risk Reduction (UNDRR): UNDRR facilitates international co-operation and co-ordination on disaster risk reduction through initiatives such as the Sendai Framework for Disaster Risk Reduction. UNDRR works with member states, regional organisations and other stakeholders to strengthen risk assessment capacities and promote resilience-building efforts globally.

World Bank Group: The World Bank Group supports risk assessment and resilience-building efforts in developing countries through various initiatives and projects. This includes providing technical assistance, funding and expertise to help countries assess disaster risks, develop risk management strategies, and implement resilience measures.

International Monetary Fund (IMF): The IMF works with member countries to assess the economic impacts of natural disasters and supports efforts to strengthen disaster risk management and resilience. Through technical assistance, capacity-building programmes and policy advice, the IMF helps countries integrate disaster risk considerations into their macroeconomic and fiscal policies.

Asian Development Bank (ADB): ADB collaborates with member countries in the Asia-Pacific region to enhance disaster risk assessment and resilience-building efforts. ADB provides financial and technical assistance for risk assessment studies, capacity-building initiatives and infrastructure projects aimed at reducing vulnerability to natural disasters.

European Union (EU): The EU supports risk assessment and resilience-building efforts in its member states and partner countries through various programmes and initiatives. This includes funding research projects, providing technical expertise, and promoting best practices in disaster risk management and resilience building.

International Federation of Red Cross and Red Crescent Societies (IFRC): IFRC works with national Red Cross and Red Crescent societies and other partners to support risk assessment and resilience-building efforts at the community level. IFRC provides training, resources and technical support to enhance community-based risk assessment capacities and promote local resilience-building initiatives.

United Nations Development Programme (UNDP): UNDP supports risk assessment and resilience-building efforts in developing countries through initiatives such as the Climate Risk Early Warning Systems (CREWS) programme. UNDP works with national governments, regional organisations and other stakeholders to strengthen early warning systems, enhance risk assessment capacities, and promote climate resilience.

Source: Official information from each organisation.

Monitoring and measuring impacts

Measuring the positive impacts of resilient infrastructure serves a dual purpose: to demonstrate to society the benefits of such infrastructure on economic growth, social welfare and sustainability, while also highlighting the costs avoided by mitigating the impacts of natural disasters. This rationale underscores the importance of disseminating information on the positive outcomes of efforts to enhance infrastructure resilience, thereby fostering acceptance and support from authorities and communities alike. Three key types of positive indicators support this goal and rationale:

- **Economic growth impacts.** These indicators highlight the contribution of resilient infrastructure to economic growth by reducing disruptions such as blackouts, thereby enabling businesses to continue operating and fostering overall economic development.
- **Social welfare impacts.** Resilient infrastructure ensures continuity of essential services, such as communication networks, even in the face of natural disasters, benefiting communities, especially smaller ones, and enhancing social welfare. Some resilience measures, notably nature-based solutions, also promote further societal benefits such as health improvements due to, for instance, improved air quality, and recreational activities (OECD, 2021[16]; OECD, 2024[12]).
- **Sustainability impacts**. Resilient infrastructure initiatives can also contribute to sustainability goals by reducing emissions and minimising environmental impacts, thereby promoting a more sustainable economy and environment.

Understanding the historical record of natural disasters and their impacts is crucial for enhancing social knowledge and acceptance of the necessity for investing in resilient infrastructure. This includes recognising the upfront costs associated with resilience measures and comparing them to the costs of inaction. Moreover, it involves considering infrastructure resilience investments in terms of their opportunity costs, and improving resource allocation efficiency by directing investments toward areas where they will have the most significant impact on mitigating the effects of natural disasters.

Monitoring the impact of disaster impacts over time provides valuable insights into recurring patterns and regional vulnerabilities, aiding in the development of informed disaster preparedness plans for better future event handling. It also enables authorities to allocate resources more efficiently, prioritising response efforts where most needed. Monitoring and impact measurement should be multi-dimensional, going beyond the impacts on infrastructure assets and taking into account impacts on livelihoods and diverse community needs. It is important that impact monitoring and assessment also takes into account local stakeholders’ perspectives to ensure community empowerment.

Monitoring and measuring impacts contributes to:

- **Rational resource allocation**. Allocating resources based on the severity and nature of disasters ensures proportionate and effective distribution, minimising unnecessary wastage.
- **Risk mitigation.** Historical data on the impact of disasters helps identify high-risk areas and implement targeted mitigation strategies.
- **Community awareness.** Measuring and tracking disaster impacts raises awareness among communities about potential risks, encouraging preventive measures and better emergency preparedness.
- **Research and innovation.** Data on disaster impacts is valuable for researchers and innovators developing new technologies and strategies to enhance disaster resilience and response.

Good practices in monitoring and measuring impacts of natural disasters include:

- Comprehensive hazard identification. Identify potential hazards that could affect infrastructure, including natural disasters, technological failures, cyber-attacks and human errors.

- Expertise utilisation. Engage engineers, risk analysts and subject matter experts to accurately process and present data.
- Effective communication. Communicate risk information to stakeholders, including the public, to raise awareness and encourage proactive efforts for resilient infrastructure.
- Clear resilience goals. Establish clear and well-defined goals and objectives for infrastructure projects, encompassing positive outcomes in social, economic and environmental domains. Identifying how infrastructure resilience to natural disasters contributes to the achievement of the Sustainable Development Goals (SDGs) is of particular importance (UNDDR, 2023[17]).
- Stakeholder engagement. Involve diverse stakeholders, including communities, local authorities, experts and the private sector, in the decision-making process to identify relevant indicators and gain consensus on their importance.

Developing countries often face limitations in setting up effective monitoring and measurement systems due to lack of expertise and resources. International partnerships can be key to scale up capacities in this field. International partners can be key in supporting access, deployment and development of mechanisms and tools for comprehensive data collection, covering physical infrastructure performance, socio-economic factors, environmental impacts, and community feedback.

Box 2.6. Monitoring and measuring the impact of disasters is key for better prevention, reaction and rebuilding: The experience of Mozambique

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

To address these challenges, Mozambique has taken proactive steps to identify risks and hazards through collaboration with the National Meteorological Institute and the development of hazard maps. By utilising new data and spatial forecasting techniques, the country has been able to pinpoint areas most at risk and direct response preparation actions accordingly. Additionally, new design standards implemented in 2019 have introduced measures such as changing slopes, cutting trees and constructing levees and embankments to enhance road resilience and reduce vulnerability to natural disasters.

Source: Case study "Increasing road network resilience through adapted standards and effective use of data in Mozambique" in Chapter 3 – Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD.

Investing in capacity building and knowledge management

The construction, operation and maintenance of resilient infrastructure entail multifaceted responsibilities that demand sound data and capable individuals with the requisite expertise. Achieving resilience requires enhancing the knowledge and capabilities of all involved stakeholders. Governments need to allocate sufficient human resources to support processes conducive to resilient infrastructure development. Furthermore, adapting infrastructure to accommodate a dynamic and uncertain climate landscape will necessitate cultivating new proficiencies across various domains. Stakeholders in infrastructure should enhance their understanding of the performance of both structural and non-structural resilience measures.

The cost of maintaining and upgrading resilient infrastructure assets can be significantly minimised through a well-integrated plan developed by personnel equipped with technical expertise and an understanding of the associated risks. Such a plan should encompass all aspects of the asset management system, from policy and strategy formulation to leveraging key enablers and opportunities like nature-based solutions and technological innovations.

By enhancing the skills, knowledge and resources available to individuals, organisations and communities, capacity building empowers them to effectively tackle challenges and capitalise on opportunities. Equipping local professionals, communities and institutions with the requisite expertise and tools enables a country to autonomously plan, implement and maintain infrastructure, fostering enduring benefits and inclusive growth.

Capacities are needed in project phases including planning, design, construction, operation and maintenance. It is necessary to:

- Conduct a knowledge gap assessment. Infrastructure providers and contractors can serve as valuable partners in conducting a gap assessment to identify areas for improvement in terms of capacities needed.
- Capture, disseminate and leverage on knowledge gained from firsthand experience to enhance future infrastructure practices.

Capacity development efforts should also focus on enhancing the knowledge and skills of individuals and institutions in non-technical areas, such as disaster risk finance, policy frameworks for resilient infrastructure and other aspects related to infrastructure risk governance. This comprehensive approach ensures a well-rounded development of expertise critical for building resilient infrastructure.

A targeted approach to ensure that local communities have the capacities to plan and implement resilience-oriented actions is crucial, particularly at the local level in disadvantaged communities where the impact of disasters is often most severe due to their vulnerabilities and chronic underinvestment. These communities often lack the resources to hire professionals to plan and execute projects aimed at disaster resilience. It is essential to allocate resources equitably and build capacity within these communities to identify the challenges, develop effective solutions, and implement them. The technical assistance programmes specifically tailored to support capacity building are key components of lending strategies for infrastructure resilience. For example, the Build America Bureau in the US Department of Transport is an effective example of an institution that has evolved from financing to encompass targeted support, including training and capacity building to empower communities to take proactive measures to increase infrastructure resilience to natural disasters.

Equipping people in the public and private sector with adequate technical skills is crucial. For example, in Ghana, the Ministry of Roads and Highways has prioritised capacity building for staff through a range of training programmes to equip them with the necessary skills to effectively carry out their responsibilities. Newly recruited technical staff within the agencies undergo mandatory training programmes; this in-house training ensures that all staff, regardless of academic background, are well-prepared for their roles. Additionally, development partners such as the Japanese Development Cooperation Agency (JICA) and the African Development Bank play a significant role in supporting Ghana’s training programmes together with providing concessionary facilities for road projects. International technical cooperation, including South-South and triangular co-operation, play a crucial role in this field. Mobilising the private sector’s expertise is also crucial. For example, the International Federation of Consulting Engineers (FIDIC) carries out regular capacity building initiatives, including specialised tailored programmes for engineers and certification courses, including in developing countries.

Box 2.7. Knowledge management and impact assessment in the aftermath of disasters increases future prevention capacities: Examples from Indonesia and Japan

The Disaster Prevention Policy implemented by Indonesia aims to ensure the safe evacuation of passengers during emergencies, particularly focusing on the Mass Rapid Transit (MRT) system in Jakarta. A crucial factor contributing to the success of these projects was the emphasis on building knowledge, skills and capacities throughout the planning and construction phases, particularly regarding resilience to natural disasters.

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

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

Impact assessment studies are key components of resilience strategies. In Japan, the case study of the 2019 Abukuma River flood revealed the substantial damage incurred, including the inundation of 114 km^2, resulting in 29 fatalities and significant economic losses. The case study underscored the potential impact of unrealised investments, highlighting the importance of preventive measures in flood risk reduction strategies.

Source: Chapter 3 – Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD.

Carrying out strategic preventive maintenance

Strategic preventive maintenance in infrastructure refers to a proactive approach aimed at preventing structural weaknesses and deterioration in infrastructure assets through regular inspections, monitoring and maintenance activities. This preventive strategy involves identifying potential vulnerabilities and addressing them before they escalate into significant issues that could compromise the integrity or functionality of the infrastructure.

The goal of strategic preventive maintenance is to mitigate the risk of structural weaknesses resulting from wear and degradation, which can lead to severe damages in the face of natural disasters. Major structural damage to infrastructure not only incurs high repair costs but also leads to significant downtime, greatly reducing operational capacity. Much of this damage is attributed to pre-existing structural weaknesses exacerbated by wear and degradation over time. Natural disasters exacerbate these vulnerabilities, resulting in more extensive and costly damage that necessitates extensive repairs. However, regular preventive maintenance can mitigate wear and degradation, thereby minimising the financial and economic toll of disaster recovery.

By implementing strategic preventive maintenance, countries minimise the risks of failures, extend the lifespan of assets, optimise performance, and reduce overall maintenance costs over the long term.

By monitoring the condition of existing infrastructure and conducting regular inspections and maintenance, structural weaknesses can be mitigated, significantly reducing the damage incurred during disaster events. Regular Preventive Maintenance (RPM) is estimated to decrease life-cycle maintenance costs by 32% compared to reactive maintenance (MLIT, 2018[18]). RPM contributes to improved infrastructure quality during operation by minimising wear and degradation. This becomes particularly crucial in the aftermath of disaster events, as the infrastructure can remain operational, albeit potentially at reduced capacity, facilitating broader relief efforts and aiding disaster recovery in affected areas.

RPM is also more manageable compared to extensive post-disaster repairs, as engineers perform similar tasks regularly. This streamlined process enhances efficiency, saving both time and money, and enables the infrastructure to remain fully operational for extended periods. Moreover, this accumulated experience allows for the development of strategies to minimise disruptions during repairs, further reducing the economic impact.

Enabling conditions for effective strategic preventive maintenance in infrastructure include clearly defining responsibilities among stakeholders and holding them accountable for both maintenance and repairs. For instance, in a public-private partnership (PPP), the private firm responsible for construction can also be held accountable for a portion of maintenance costs during the initial years of operation, incentivising them to prioritise preventive maintenance strategies from the outset.

Incentives play a crucial role in encouraging stakeholders to prioritise maintenance. One approach involves linking maintenance responsibilities to the construction phase, where those responsible for construction bear a share of maintenance and repair costs. Additionally, incentives can focus on promoting maintenance techniques that facilitate quick repairs with minimal disruption to service, thus ensuring continuous infrastructure functionality.

Furthermore, the development of innovative maintenance techniques that minimise disruptions is essential. With the need for more frequent repairs under preventive maintenance, there is a greater opportunity to invest in technologies and methods that streamline repair processes without compromising infrastructure operations.

Strategic preventive maintenance requires:

- **Clear accountability**. Defining clear responsibilities among stakeholders and institutions ensures that those responsible for maintenance are also held accountable for repairs. This accountability can be reinforced through contractual agreements, such as in public-private partnerships (PPP) where maintenance obligations are integrated into construction contracts.
- **Incentives alignment**. Aligning incentives with maintenance goals is crucial for promoting proactive maintenance practices. For example, linking maintenance responsibilities to the construction phase can incentivise construction firms to prioritise quality and durability, knowing they will bear a portion of maintenance costs during the operational phase.
- **Proactive investment**. Investing in preventive maintenance techniques and technologies is essential for minimising disruptions and extending the lifespan of infrastructure. By allocating resources to regular inspections, proactive repairs, and predictive maintenance strategies, stakeholders can mitigate the risk of major structural damage and costly post-disaster repairs.
- **Continuous improvement**. Emphasising continuous improvement in maintenance practices allows stakeholders to adapt and evolve their strategies over time. This includes investing in research and development to identify innovative maintenance techniques that minimise service disruptions and optimise infrastructure performance.
- **Collaboration and knowledge sharing**. Facilitating collaboration and knowledge sharing among stakeholders fosters a culture of best practices and lessons learned. By sharing experiences, successes and challenges, stakeholders can collectively improve maintenance efficiency and effectiveness across different infrastructure projects and sectors.

Box 2.8. Japan invests in preventive maintenance to enhance infrastructure resilience

Japan's regulatory framework advocates a life cycle approach to maintenance, emphasising proactive measures to address issues before they escalate. Adopting this approach can yield a 32% reduction in overall maintenance costs compared to reactive methods, enhancing infrastructure quality during its operational lifespan.

Clear legal and policy frameworks are pivotal in ensuring cohesive maintenance efforts across governmental levels. This clarity fosters efficient co-ordination and resource allocation for infrastructure upkeep.

Japan prioritises conducting repairs during operation to minimise disruptions, thereby mitigating economic costs associated with downtime.

Leveraging automated systems and sensors enables early detection of failures, facilitating prompt maintenance interventions and substantially reducing maintenance expenses.

Through a strategic mix of regulatory, legal and operational measures, Japan exemplifies the efficacy of proactive maintenance practices in safeguarding its infrastructure against natural disasters and the challenges of ageing assets.

Source: Case study "Investing in cutting edge technology and strategic preventive maintenance to build resilience in a cost-effective way in Japan" in Chapter 3 – Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD.

Deploying cutting-edge technology and fostering new design and innovation

Advanced technology, digitalisation, innovation and novel infrastructure design contribute to increasing infrastructure resilience to natural disasters by making it more capable of withstanding natural disasters such as floods, earthquakes and hurricanes. This can reduce the risk of damage, disruption and loss of life during extreme events. In addition to increased resilience, they also contribute at the same time to:

- **Cost-effectiveness.** Some new design and innovations offer cost-effective solutions compared to traditional infrastructure designs. For example, nature-based solutions, such as water retention ponds or green roofs and walls, can provide multiple benefits, including flood mitigation and improved water quality, at a lower cost than conventional grey infrastructure (OECD, 2020[19]).
- **Sustainability.** Many new design innovations prioritise sustainability by incorporating eco-friendly materials, energy-efficient technologies, and nature-based solutions. This aligns with sustainable development goals and reduces the environmental impact of infrastructure projects in developing countries.
- **Adaptability.** Innovative designs often offer greater adaptability to changing environmental conditions and evolving risk factors. Modular construction techniques, for example, allow for the rapid assembly and disassembly of infrastructure components, enabling quick responses to disasters and changing needs.

Cutting-edge technology provides advanced monitoring, real-time data analytics and predictive capabilities, which can aid in identifying vulnerabilities, assessing risks and facilitating timely responses. Furthermore, leveraging advanced technologies can enhance various aspects of resilience, ranging from minimising disruption during maintenance to enhancing the physical durability of the infrastructure itself.

Resilient infrastructure equipped with advanced monitoring and maintenance capabilities can mitigate costly damages and minimise extensive repair and recovery expenses during disaster events. Despite potentially high initial investments in cutting-edge technology, the long-term benefits often outweigh the costs. In particular, the use of cutting-edge technology is at the foundation of increased preparedness, reaction and rebuilding capacity through:

- **Early warning systems.** Modern technology enables the deployment of early warning systems capable of detecting hazards and providing real-time alerts to authorities and the public. Sophisticated sensors can detect seismic activity, monitor water levels in flood-prone areas, and identify infrastructure wear and tear, allowing proactive measures to be implemented before disasters occur.
- **Data-driven and risk-informed decision making.** Cutting-edge technology facilitates the collection and analysis of large volumes of data related to infrastructure performance and environmental conditions. Leveraging data-driven decision-making processes enables optimal resource allocation and prioritisation of maintenance efforts.
- **Smart and adaptive Infrastructure.** Integration of smart technologies such as the Internet of Things (IoT), artificial intelligence (AI) and machine learning (ML) enables infrastructure to become more adaptive and self-modifiable. Examples include smart grids that automatically reroute power during outages and self-healing concrete that can autonomously repair cracks.
- **Energy efficiency and sustainability.** Advanced technologies, from materials to construction machines, often offer more energy-efficient solutions, leading to cost savings and reduced environmental impact. Incorporating renewable energy sources, energy storage systems and smart energy management systems allows resilient infrastructure to better withstand energy supply fluctuations and contribute to sustainability.

In addition to the use of cutting-edge and digital technologies, design and innovation play a significant role in making infrastructure resilient to natural disasters by integrating features that enhance its ability to withstand and recover from adverse events. Innovation and design can contribute to enhancing infrastructure resilience to natural disasters through:

- **Increasing adaptability and flexibility.** Innovative designs allow infrastructure to adapt to changing environmental conditions and unexpected events. Flexible designs can accommodate variations in load, stress and environmental factors, reducing the risk of structural failure during disasters.
- **Ensuring redundancy and backup systems.** Innovative designs often incorporate redundant systems and backup mechanisms to ensure continued functionality during disruptions. For example, redundant power sources or communication networks can maintain essential services even if primary systems are compromised.
- **Providing modularity and scalability.** Modular designs allow infrastructure to be easily expanded or modified in response to evolving needs or changing conditions. This scalability ensures that infrastructure can grow or adapt over time, enhancing its resilience to shifting environmental and socio-economic factors.
- **Harnessing the potential of nature-based solutions.** Innovative designs increasingly incorporate nature-based solutions that mimic natural processes to enhance resilience. Examples include green roofs, permeable pavements and constructed wetlands, which can mitigate flood risks, improve water management and enhance ecosystem services (OECD, 2020[19]; OECD, 2021[16]).
- **Fostering the use of advanced materials and construction techniques.** Innovations in materials, science and construction techniques enable the development of infrastructure that is more resistant to hazards such as earthquakes, floods and extreme weather events. High-performance materials and construction methods enhance structural integrity and durability, reducing vulnerability to damage and collapse.

- **Integrated risk assessment and design.** Innovative design approaches integrate risk assessment and hazard mitigation strategies into the design process. By considering potential hazards and vulnerabilities from the outset, infrastructure can be designed to minimise risks and enhance resilience.

Innovation and design play a critical role in enhancing the resilience of infrastructure to natural disasters by incorporating adaptability, redundancy, modularity, nature-based solutions, advanced materials and integrated risk assessment. By embracing innovative designs, infrastructure can better withstand and recover from the impacts of disasters, ultimately safeguarding communities and promoting sustainable development. Some examples include:

- **Floating buildings and bridges.** In flood-prone areas, engineers are designing buildings and bridges that can float during floods, reducing the risk of damage and allowing for continued functionality during and after the event. For example, the "Floating Pavilion" in Rotterdam, Netherlands, is a multi-purpose structure designed to rise with floodwaters, providing a resilient space for events and activities.
- **Nature-based solutions.** Incorporating green infrastructure elements such as green roofs, rain gardens and permeable pavements helps manage stormwater runoff and reduce flooding risks. These nature-based solutions enhance resilience by absorbing and filtering water, reducing the burden on traditional drainage systems (OECD, 2020[19]) .
- **Seismic-resistant structures.** In earthquake-prone regions, engineers are implementing innovative seismic-resistant design techniques to minimise structural damage and ensure occupant safety. Examples include base isolators, which decouple the building from the ground motion, and damping systems, which dissipate seismic energy.
- **Smart infrastructure.** Smart infrastructure systems leverage sensors, data analytics and automation to monitor and manage infrastructure assets in real-time. For example, smart grids in the energy sector use advanced sensors and predictive analytics to detect and respond to power outages, improving resilience and reliability.
- **Resilient coastal infrastructure.** Coastal infrastructure, such as seawalls, breakwaters and artificial reefs, are being designed with resilience in mind to withstand storm surges, erosion and sea-level rise. Innovative designs incorporate natural materials and bioengineered solutions to enhance coastal protection and preserve ecosystem services.
- **Adaptable modular construction.** Modular construction techniques allow for the rapid assembly and disassembly of buildings and infrastructure components, enabling quick responses to changing conditions and emergencies. Prefabricated modular units can be easily transported and assembled, providing flexible and resilient solutions in disaster-prone areas.
- **Earthquake-resistant bridges.** Advanced bridge designs incorporate seismic-resistant features such as flexible columns, energy-dissipating devices, and innovative materials to withstand ground shaking and ensure structural integrity during earthquakes. For example, the Akashi Kaikyō Bridge in Japan utilises seismic isolation bearings to absorb earthquake forces and maintain stability.

The main challenges that developing countries face in using cutting-edge technology to innovate and apply novel design to ensure infrastructure resilience to natural disasters include:

- **Limited resources.** Developing countries often face resource constraints, including limited funding, technical expertise and access to technologies, innovation and novel designs. This can hinder the adoption of new design innovations that require significant investment or specialised knowledge. In particular, cutting-edge technology often comes with high initial costs, which may be prohibitive for developing countries with limited financial resources.
- **Capabilities and know-how.** Developing countries may lack the necessary technical expertise and human resources to adopt and maintain cutting-edge technology for infrastructure resilience. Building

the capacity of local engineers, architect, and construction workers to implement new design innovations is essential but challenging in developing countries. Training programmes, knowledge-sharing initiatives and technology transfer partnerships are needed to address this capacity gap.

- **Access and availability.** Access to technology and expertise may be limited in developing countries, making it difficult to acquire and implement these solutions effectively. In some locations inadequate infrastructure and connectivity may hinder the adoption and integration of advanced technology solutions.
- **Regulatory barriers.** In some cases, outdated or rigid regulatory frameworks may pose barriers to the adoption of innovations. Streamlining approval processes and updating building codes and standards to incorporate resilient design principles can help overcome these regulatory challenges. A legal vacuum with respect to digital and other advanced technologies can also hamper their utilisation potential in developing countries.
- **Socio-economic factors.** Socio-economic factors such as poverty, inequality and informal settlements can complicate the implementation of new design innovations in developing countries. Addressing these factors requires comprehensive approaches that consider social, economic, and cultural contexts.

Box 2.9. The role of nature-based solutions (NBS) in the climate resilience of infrastructure

Different definitions of NBS exist. OECD defines NBS as measures that protect, sustainably manage or restore nature, with the goal of maintaining or enhancing ecosystem services to address a variety of social, environmental and economic challenges. NBS can contribute to the climate resilience of infrastructure by:

- Strengthening overall resilience of infrastructure networks and protecting people by complementing grey solutions. For example, around Tanzania's capital, Dar es Salaam, a combination of NBS (restoration of 3 000 square metres [m^2] of coral reefs and 1 245 ha of mangroves) and grey infrastructure (2.8 km of sea walls, groynes and sea defence structures) provide protection from sea level rise and rain-induced flooding, directly benefiting around 58 000 people (UNEP, 2022[20]).
- Protecting grey infrastructure assets, ensuring their safe functioning and enhancing their operable life. In the Philippines, mangroves act as living safeguards to avert more than USD 1 billion in damage to residential and industrial infrastructure, while protecting over 600 000 people from flooding annually.
- Providing flexible and adaptive solutions in the context of climate change. NBS also have the potential to recover their functions following extreme weather events. For example, coastal wetlands can migrate upwards in response to rising seas (if sea level rise is within certain limits and there is undeveloped space to expand) (Borchert et al., 2018[21]).

Estimates show that NBS for infrastructure can cost half as much as grey alternatives, while generating 28% more in added value (Bassi et al., 2021[22]). Moreover, through enhancing human well-being and the quality of life in diverse ways, NBS also provides important social co-benefits, including health outcomes. However, NBS solutions are still used largely at pilot scales. To promote wider uptake of NBS, national governments need to design innovative institutional, policy, regulatory and financial frameworks. These should enable the use of NBS by both public sector agencies and authorities, as well as private actors.

Source: Based on OECD (2024[12]), "Harnessing Nature-based Solutions for climate-resilient infrastructure" in *Infrastructure for a Climate-resilient Future*.

To overcome these challenges, developing countries need:

- **Financial support.** Financial assistance from MDBs and DFIs and donor countries to offset the initial costs of acquiring cutting-edge technology can be a game changer in facilitating the adoption.
- **Technology transfer and partnerships**: Establish partnerships with technology providers, research institutions and developed countries to facilitate technology transfer and capacity building.
- **Training and education.** Invest in training programmes and educational initiatives to build local capacity and expertise in utilising and maintaining cutting-edge technology for infrastructure resilience.
- **Policy and regulatory support.** Develop policies and regulatory frameworks that encourage investment in resilient infrastructure and incentivise the use of cutting-edge technology through tax breaks, subsidies and other incentives. A regulatory framework that mandates and incentivises the integration of advanced technologies into the planning and construction process. For instance, implementing a bidding system that rewards the utilisation of advanced technologies could be effective. Another complementary approach is the support provided by multilateral agencies and countries, which facilitate the connection between infrastructure providers and investors offering cutting-edge technology solutions.
- **Collaboration and knowledge sharing.** Foster collaboration among government agencies, private sector entities, academic institutions and international partners to share knowledge, best practices and lessons learned in implementing cutting-edge technology solutions.

Despite these challenges, the advantages of utilising new design innovations for resilient infrastructure outweigh the barriers. With strategic planning, investment and collaboration, developing countries can leverage innovative design solutions to build infrastructure that is more resilient, sustainable, relevant for the specific context and adaptable to the impacts of natural disasters.

Developing countries are often characterised by rich biodiversity and diverse ecosystems that provide vital services to local communities, including food security, clean water and climate regulation. However, rapid urbanisation, industrialisation and unsustainable land use practices have placed immense pressure on these ecosystems, leading to habitat destruction, deforestation and loss of biodiversity. As a result, many developing countries are experiencing heightened vulnerability to natural disasters, exacerbated by the degradation of infrastructure.

Preserving and restoring ecosystems in developing countries is therefore crucial for building resilience to natural disasters. Nature-based solutions (NBS) offer a sustainable approach to addressing this challenge by leveraging the inherent resilience of natural systems. For example, reforestation efforts can help stabilise slopes and reduce the risk of landslides and soil erosion in mountainous regions prone to heavy rainfall and seismic activity. Additionally, restoring mangrove forests along coastlines can provide a natural buffer against storm surges and coastal erosion, protecting coastal communities and critical infrastructure from the impacts of hurricanes and tsunamis.

Furthermore, developing countries often face significant infrastructure gaps, particularly in vulnerable regions where the need for resilient infrastructure is most acute. Traditional grey infrastructure solutions, such as concrete flood barriers and levees, are often costly to construct and maintain, and may have limited effectiveness in the face of increasingly unpredictable and extreme weather events. In contrast, nature-based solutions offer a cost-effective alternative that can complement or replace traditional infrastructure, providing multiple benefits such as flood control, water purification and carbon sequestration while enhancing ecosystem health and biodiversity.

By integrating nature-based solutions into infrastructure planning and development, developing countries can address both their infrastructure gaps and environmental challenges while building resilience to natural disasters. This approach not only offers tangible benefits in terms of disaster risk reduction and climate adaptation but also contributes to broader sustainable development goals by safeguarding ecosystems, promoting biodiversity and enhancing the well-being of local communities.

Digitalisation, innovation, and design play a critical role in enhancing the resilience of infrastructure to natural disasters by incorporating adaptability, redundancy, modularity, nature-based solutions, advanced materials and integrated risk assessment. By embracing innovation and modernisation, infrastructure can better withstand and recover from the impacts of disasters, ultimately safeguarding communities and promoting sustainable development.

Box 2.10. Re-building effectively through technology and international partnerships in Ghana

In response to the pressing need for a substation adjacent to Accra’s thriving commercial hub, Ghana faced a dual challenge of land scarcity and heightened flood risk in available areas. To overcome this hurdle, Japan played a pivotal role through JICA, extending significant support in the form of a JPY 4.2 billion (Japanese yen) grant for the construction and retrofitting of the substation. Collaborating with the Ghanaian government, Mitsubishi took charge of the construction and retrofitting efforts, leveraging innovative technology and methods to minimise disruptions to commercial activities. These efforts included the use of underground drilling techniques and the installation of crucial flood and disaster mitigation technologies such as automated pumps and fire-resistant walls. These measures not only facilitated the station’s construction but also proved instrumental in mitigating the impact of subsequent floods, ensuring uninterrupted power supply to the commercial hub.

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

Source: Case study “Building a bulk supply point in a flood-prone area in Accra, Ghana” in Chapter 3 – Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD.

Conclusions

Ensuring infrastructure resilience to natural disasters is context- and time-specific. However, some general good principles apply and when implemented have significant impact on the quality, effectiveness and efficiency of the preventive, reaction and re-building actions. This project highlights the value of exchanging experiences to identify lessons learned and innovative approaches to enhance resilience to natural disasters. By sharing knowledge and identifying best practices that can be customised to local conditions, countries can effectively address their unique challenges while benefiting from proven strategies implemented elsewhere. The project has demonstrated that while each country faces distinct socio-economic, environmental and institutional realities, there are common principles and approaches that can be universally applied to improve infrastructure resilience to natural disasters.

By fostering a culture of knowledge sharing and mutual learning, this project contributes to building a repository of effective strategies and tools that can be adapted and implemented in diverse settings to enhance infrastructure resilience. In particular, seven good practices have been identified:

- Adopting a life cycle approach
- Ensuring interests’ alignment through effective collaboration
- Conducting risk assessment

- Monitoring and measuring impacts
- Investing in capacity building and knowledge management
- Carrying out strategic preventive maintenance
- Deploying cutting-edge technology and fostering new design and innovation

Adopting a life cycle approach is essential for ensuring infrastructure resilience to natural disasters because it requires taking into account the various stages of an infrastructure project, from planning and design to operation and maintenance. This approach enables proactive measures to be incorporated into the project, leading to long-term sustainability and resilience.

Effective collaboration among stakeholders and countries is crucial as it ensures alignment of interests and promotes collective action towards resilience goals. By bringing together diverse expertise, resources and perspectives, collaboration facilitates comprehensive risk assessment and the development of robust mitigation strategies.

Conducting risk assessment and measuring impacts are fundamental steps in understanding natural hazard risks and vulnerabilities and identifying areas for improvement. These practices provide valuable insights into the potential consequences of natural disasters, guiding informed decision making and resource allocation.

Investing in capacity building and knowledge management is key to enhancing the resilience of infrastructure. By empowering individuals and organisations with the necessary skills and information, countries can strengthen their ability to plan, implement and maintain resilient infrastructure solutions.

Strategic preventive maintenance, coupled with the deployment of cutting-edge technology and fostering innovation in design, plays a critical role in minimising vulnerabilities and ensuring resilience and longevity of infrastructure assets. These practices enable proactive maintenance and upgrade activities by capitalising on new and more efficient technologies, designs and materials, reducing the risk of costly damages and disruptions during natural disasters.

These good practices provide actionable guidance for prevention, reaction and rebuilding operations, increasing overall disaster preparedness and response, enabling countries to mitigate risks and minimise damages. In addition, to improve national and local policy approaches in developing countries, international co-operation is vital for supporting developing countries in implementing these good practices. Developing countries often face significant challenges in terms of limited financial resources, technical expertise and institutional capacities. International co-operation can provide much-needed financial assistance, technical know-how and capacity-building support to help these countries overcome these barriers and effectively implement resilience-building measures. An increased collective effort of the global community, including national and international development banks, and financial institutions is needed to enhance developing countries' resilience to natural disasters, protect critical infrastructure, and promote sustainable development for the benefit of present and future generations worldwide.

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3 Making infrastructure resilient to natural disasters: Learning from concrete projects in Africa, Asia, Latin America and the OECD

This chapter examines seven concrete infrastructure projects from Colombia, Ghana, India, Indonesia, Japan, Mozambique and the United States, each offering valuable insights into effective strategies and practices to enhance prevention, reaction and rebuilding efforts for resilience to natural disasters. It discusses the restoration of a degraded ecosystem and the upgrading fluvial transport systems in Colombia; the construction a power station in a flood-prone area in Ghana; the use of risk assessment to enhance prevention capacities in Mozambique; the adaptation of assets design and increasing user awareness in urban public transport in Indonesia; the integration of environmental preservation criteria in highway construction in India; the incentives and regulations for aligning interests and achieving cost-sharing in a flood-diversion project in the United States; and the use of strategic preventive maintenance and digital technology for infrastructure resilience in Japan. Through step-by-step analysis of these infrastructure projects this chapter provides valuable in-depth lessons for governments, the private sector, and civil society on how to effectively prevent, react and re-build to ensure infrastructure resilience to natural disasters.

Introduction

Determining resilient designs suitable for a specific country or community, addressing the affordability of infrastructure in developing nations, and prioritising infrastructure projects pose significant challenges. To address these complexities, concrete case studies from seven countries – Colombia, Ghana, India, Indonesia, Japan, Mozambique and the United States – are examined within the framework of the three pillars of prevention, reaction and rebuilding.

Chapter 3 delves into detailed descriptions of these case studies, covering a wide range of infrastructure projects and national policies. The cases span various categories such as transportation, energy, canal and flood diversion, and maintenance efforts, offering a comprehensive analysis of infrastructure resilience from diverse geographical perspectives in Africa, Asia, Latin America and the OECD.

Table 3.1. Overview of the infrastructure projects discussed in this Compendium, selected countries, 2024

Countries	Case studies	P	R	R
Colombia	Restoring a degraded ecosystem and preventing flooding in the Dique Canal to ensure community well-being and productivity	■		■
Ghana	Reacting to an emergency and increasing preparedness by building a power-station in the capital district during a flood	■	■	
India	Reducing vulnerabilities through quality controls and technology to ensure road transport network stability	■		
Indonesia	Reducing vulnerabilities and increasing preparedness by detailed analysis and facility design improvement of the urban transport	■	■	
Japan	Reducing vulnerabilities and increasing preparedness through strategic preventive maintenance and use of cutting-edge technology in transport infrastructure	■		■
Mozambique	The use of data to map hazard zones to minimise the disruption of flood and cyclones on road networks through pre-emptive preparation	■	■	
United States	Reducing vulnerabilities and increasing preparedness to ensure road transport network stability through reducing peak flooding	■		

Note: PRR (Prevent, React, Rebuild) are the three key areas that are linked to making infrastructure resilient to natural disasters. Prevent area is linked to actions, tools and physical characteristics of the infrastructure that enable damage prevention and/or minimisation, including strategic preventive maintenance. React area is linked to the actions taken and tools used in response to a natural disaster to restore operational capacity and mitigate service provision disruption, such as by providing alternative infrastructure options in the short term. Rebuild area is linked to actions, tools and plans, including changes in the physical characteristics of the infrastructure, that shape how the disrupted infrastructure is rebuilt with the aim of looking forward. In the case of developing countries, damaged infrastructure in the aftermath of a natural disaster can often be rebuilt different to its original construction, shifting process, materials and even purpose of the infrastructure to consider shifting economic, environmental, and social demands, allowing it to promote transformative economic growth whilst becoming more environmentally sustainable socially inclusive.
Source: Authors' elaboration based on the case studies presented in this chapter.

By analysing these cases, this chapter aims to provide practical insights into how different countries have approached infrastructure resilience challenges. Through step-by-step analyses of each case, valuable lessons emerge, shedding light on effective strategies and practices that can be applied across different contexts. Ultimately, this discussion contributes to a deeper understanding of the complexities involved in enhancing infrastructure resilience worldwide.

The following seven sections present the seven case studies. Each case study is presented following a similar structure: the context and the challenges to be addressed, the innovative solutions implemented and the achieved results.

Restoring a degraded ecosystem and preventing flooding in the Dique Canal in Colombia to support economic and social development

The restoration of the Dique Canal represents a multifaceted endeavor aimed at revitalising a historically significant waterway while addressing contemporary challenges, restoring a degraded ecosystem and preventing flooding. By leveraging innovative solutions and collaborative partnerships, the restoration project has the potential to deliver lasting benefits in terms of transportation efficiency, environmental conservation and regional development.

An historical infrastructure which remains pivotal for regional economic development today

The Dique Canal, a 117 km inland waterway connecting the Magdalena River and the bay of Cartagena, was originally constructed in 1582 and later rebuilt in 1650 due to inadequate maintenance. Historically, it has held significant geopolitical and economic importance as a vital artery for shipping transportation. The canal played a pivotal role in fostering the growth of Cartagena as a thriving trading port city. However, over time, sedimentation issues hampered its usability, and the emergence of land transport alternatives diminished its relevance.

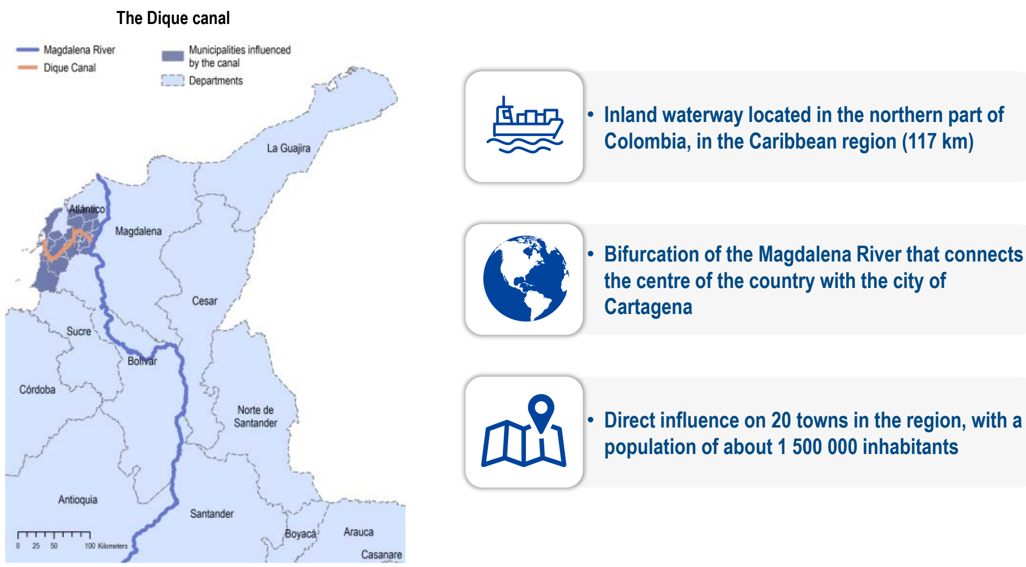
Neglected maintenance and poor management further exacerbated the canal's decline, rendering it inactive for an extended period. Nevertheless, recognising its potential benefits in flood control, water utilisation, transportation and environmental conservation, the National Planning Department of Colombia as part of the National Development Plan and in collaboration with Unit for Disaster Risk Management is responsible for the planning of the restoration of the canal, while the implementation is headed by the National Infrastructure Agency with collaboration from multiple stakeholders.

The restoration plan encompasses various measures, including regulating water inflow, managing sediment transit, ensuring navigational conditions, enhancing marshes and river connectivity, and rehabilitating the degraded ecosystem.

The restoration of the Dique Canal holds promise for revitalising its role as a crucial transportation artery and bolstering regional development (Figure 3.1). By addressing sedimentation challenges and implementing sustainable management practices, the canal is expected to facilitate efficient waterborne transportation, promoting trade and economic activity in the region. Furthermore, the restoration efforts are poised to yield significant environmental benefits, including improved flood control measures, optimised water resource utilisation, and the restoration of degraded ecosystems along the canal's route.

The revitalisation of the Dique Canal aligns with broader efforts to enhance regional connectivity and infrastructure resilience (OECD, 2022[1]). As part of a comprehensive national development strategy, the restoration project contributes to strengthening the region's transportation network and bolstering its resilience to natural disasters and climate change impacts. By integrating flood control measures and ecosystem restoration initiatives, the project demonstrates a holistic approach to infrastructure development that prioritises environmental sustainability and community resilience.

Figure 3.1. Location and background of the Dique Canal project, Colombia



Source: Authors' elaboration based on "Restoration of the Degraded Ecosystems of the "Canal del Dique", presentation by Miguel Gallego, Deputy Director for prospective studies and national development, National Planning Department (DNP), Colombia at the 2nd preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Planning, Financing, and Building Infrastructure Resilient to Natural Disasters that took place on 7 September 2023.

Due to inadequate maintenance of the Dique Canal, the surrounding area has experienced numerous challenges, including the loss of hydraulic connectivity and the inability to regulate floodwaters effectively This deficiency led to a significant flood event in 2010/11, resulting from a breach of the levee system, which adversely affected over 700 000 residents. Additionally, the canal has faced issues related to uncontrolled sediment inflow from the Magdalena River, exacerbating flood risks and causing damage to the coral system in Cartagena Bay.

The Dique Canal holds critical importance beyond flood control, serving as an essential inland waterway for transportation and a livelihood for local fishermen; it also serves as a vital source of fresh water for the city of Cartagena.

Considering these challenges and the canal's essential role in the region, addressing the maintenance and management of the Dique Canal is imperative. Implementing comprehensive restoration measures, including sediment control, hydraulic infrastructure upgrades, and ecosystem conservation initiatives, is essential to mitigate flood risks, preserve ecological integrity and sustainably manage water resources in the area. Additionally, ensuring adequate maintenance of the canal's infrastructure is crucial to safeguarding its functionality and resilience in the face of future hydrological challenges and climate-related hazards.

A comprehensive prevention action to mitigate the impact of climate change and natural disasters and foster regional economic development

By revitalising the canal and implementing comprehensive flood prevention measures, the project aims to safeguard communities, infrastructure and ecosystems from the devastating consequences of inundation events. The project started in June 2023 with the signing of the public-private partnership (PPP) agreement between the National Infrastructure Agency of Colombia and the Ecosistemas del Dique consortium, and is expected to be completed in 180 months. The restoration of the Dique Canal is undertaken as a strategic project in the framework of CONPES 4060 of 2021, which aims to establish a management model for the development of concessions based on the principles of intermodality, and institutional, financial, social and environmental sustainability.

One of the primary ways the restoration project contributes to flood prevention is by enhancing the canal's capacity to regulate water inflow. Through the construction of modernised facilities, such as water gates, sluice gates and spillways, the project enables effective control over the volume and flow of water entering the canal. By regulating water inflow, authorities can manage water levels within the canal system, minimising the risk of overflow and subsequent flooding during periods of heavy rainfall or river discharge.

Additionally, flood prevention works are integral to the restoration project, encompassing a range of engineering and infrastructure interventions designed to mitigate flood risks along the canal's route. These measures may include the construction of levees, embankments and floodwalls to contain floodwaters and prevent inundation of adjacent lands. Furthermore, dredging activities may be undertaken to deepen and widen the canal, improving its capacity to accommodate excess water and reduce the likelihood of flooding in downstream areas. In addition to the construction of locks, the restoration project will include the implementation of a gate system designed to regulate sediment flow, as well as comprehensive flood and erosion prevention measures. These measures will encompass the construction of dikes and hydraulic gates, facilitating connectivity between marshes and the river system. To address flood prevention, the project sets a return period of 100 years, considering potential sea and river water rise resulting from climate change.

The restoration project incorporates nature-based solutions for flood prevention, such as wetland restoration and riparian zone management. By restoring and enhancing natural habitats along the canal's banks, including marshes, mangroves and riparian forests, the project promotes natural flood attenuation processes. These habitats act as natural buffers, absorbing excess water, reducing peak flows, and providing valuable ecological functions that help mitigate flood risks while enhancing biodiversity and ecosystem resilience. Furthermore, restoration efforts will focus on reestablishing connections between marshes and the river, undertaking cleaning operations within the canal, and rehabilitating mangrove ecosystems. Additionally, the construction of fish passages will be implemented to enhance natural ecosystems and promote biodiversity. These interventions are integral to the restoration project's goal of improving ecological resilience and fostering the recovery of degraded habitats.

Overall, the combination of infrastructure development, flood prevention measures and ecosystem restoration initiatives underscores the comprehensive nature of the restoration project. By integrating engineering solutions with ecological restoration efforts, the project aims to enhance the resilience of the Dique Canal ecosystem while mitigating the impact of natural disasters and promoting sustainable management practices.

Collaboration and the smart use of data stand out as good practices

A distinctive feature of this project is that it is multipurpose. The project is conceived in a holistic way and actions aimed at increasing resilience to natural disasters contribute and are compounded by actions aimed at fostering regional economic development. Each purpose plays a crucial role in achieving the project's overarching goals of improving water management, preserving ecological integrity, and increasing infrastructure resilience to natural disasters. The multiple actions foreseen in the project make it act, ultimately, as a key driver to increase the socio-economic well-being of local communities. In particular, the project addresses the following objectives:

- **Resilience to natural disasters**. Minimising the impact of flooding is indeed a crucial objective of the restoration project. By controlling water inflow into the system through the construction of locks, the project aims to enhance the canal's resilience to natural disasters, particularly floods. This measure helps regulate water levels, mitigate flood risks, and protect surrounding communities and infrastructure from inundation events.
- **Sustainable water management and security**. It controls sediment transit. Sedimentation is a significant issue affecting the environment of the canal and Cartagena Bay. The restoration project includes measures to control sediment transit, such as dredging activities and sediment management strategies. By addressing sedimentation, the project aims to improve water quality, preserve ecological integrity, and maintain navigability within the canal and its adjacent water bodies. It also restricts salt intrusion. Saltwater intrusion poses challenges to freshwater resources and ecosystems in coastal areas. The restoration project seeks to restrict salt intrusion into the canal system, thereby safeguarding freshwater supplies and protecting sensitive habitats from salinisation. This objective contributes to ensuring water security and ecological sustainability in the region. The project also aims at securing fresh water supply. The Dique Canal serves as a vital source of freshwater supply to the region, including the city of Cartagena. Securing and optimising freshwater supply is a fundamental purpose of the restoration project, ensuring reliable access to clean water for domestic, agricultural and industrial purposes, thereby supporting socio-economic development and public health.
- **Promotion of fishery productivity**. The restoration project aims to enhance fishery productivity within the canal and its surrounding waters. By improving water quality, preserving habitats, and implementing sustainable fishery management practices, the project seeks to promote the growth of fish populations and support the livelihoods of local fishermen, contributing to food security and economic development in the region.
- **Optimisation of navigability**. Ensuring navigability within the Dique Canal is essential for supporting transportation and commerce along its route. The restoration project includes measures to optimise navigational conditions, such as dredging, maintenance of navigation channels and infrastructure upgrades. These efforts facilitate safe and efficient navigation for commercial vessels, promoting trade and economic activity in the area.
- **Restoration of natural environment and ecosystems**. Restoring the natural environment and ecosystems along the canal corridor is a key objective of the project. This includes habitat restoration, reforestation and conservation initiatives aimed at enhancing biodiversity, preserving ecological functions and promoting the resilience of natural ecosystems. By restoring degraded habitats and protecting valuable natural assets, the project contributes to ecological sustainability and environmental resilience in the region.

In addition to the holistic approach, the international peer dialogue activities carried out in the framework of the preparatory work for this compendium have identified that this project stands out in the following good practice areas:

- **Risk and impact assessment.** The comprehensive risk and impact assessment and the understanding of the negative impacts of climate change and natural disasters, notably the significant flood in 2010/11 of the area surrounding the Dique Canal, lay a solid foundation for the project. A multitude of data and information from various sources have been meticulously analysed in this broad assessment, contributing to a nuanced understanding of the challenges and opportunities associated with the project.
- **Collaboration.** The success of the project is inherently tied to the active collaboration fostered throughout its life cycle. During the project's conceptualisation, community participation was

prioritised, ensuring that local perspectives and concerns were integral to the planning process. As implementation commenced, continuous engagement with local stakeholders became a cornerstone. Despite the project's national scope, the signing of ten agreements with local governments exemplifies a commitment to co-ordinated efforts and future infrastructure sustainability. Recognising fishermen as vital stakeholders further underscores the inclusive approach, ensuring the project aligns with the needs of those directly affected. The incorporation of local stakeholders into the monitoring plan emphasises a commitment to inclusivity and transparency. By actively involving those impacted in the monitoring process, the project ensures a comprehensive evaluation of its progress and impact. This collaborative approach to measurement systems is instrumental in maintaining accountability and fostering a sense of shared responsibility for the project's success.

The ultimate effectiveness of the project will also depend on actions which go beyond the engineering activities involved in the implementation and will require the implementation of integrated flood management strategies, including early warning systems, community-based flood preparedness initiatives, and land use planning measures. These strategies aim to improve resilience and adaptive capacity at the local level, empowering communities to effectively respond to flood events and minimise the impact on lives and livelihoods. By integrating these measures with engineering interventions and ecosystem restoration efforts, the project adopts a holistic approach to flood prevention that addresses both structural and non-structural aspects of flood risk management.

Technical overview information on the project

The "Restoration of the Degraded Ecosystems of the Dique Canal" is an inland waterway infrastructure project located between the cities of "Calamar" and "Cartagena" in the Caribbean of Colombia, with a total length of 115.5 km. It consists of the construction of a pair of locks and a gates system to prevent the entry of an uncontrolled number of sediments, and also includes the restoration of the connections between the marshes and the river, and the optimisation of navigability. The project therefore serves to restore the natural ecosystems that have provided coastal populations with a means of subsistence, as well as controlling effects of floods.

The project was structured by several national entities such as the National Infrastructure Agency, the Fondo Adaptación (the entity in charge of executing all the projects to address the rainy season emergency that occurred in Colombia in 2010-11) and Cormagdalena (the organisation in charge of the Magdalena River), through the development of agreements to combine technical, administrative, social, environmental, legal, financial and risk-assessment efforts. It is a central government project headed by the National Infrastructure Agency, which is the organisation in charge of planning, co-ordinating, structuring, contracting, executing, managing and evaluating concession projects and other forms of Public-Private Partnerships (PPP) in Colombia. The project was structured from a participatory process with community leaders through more than 97 spaces for dialogue, with the support of local governments.

Project scope

- active regulation of the water inflow to the system
- sediment transit control between Cartagena's and Barbacoa's Bays with the Canal
- flood and water level control in the Canal
- control of salt intrusion
- scenarios for adaptation to climate change
- improvement of the connections between marshes and the river
- restoration of degraded ecosystems of the National Natural Parks in the area

- restoration of adjacent areas to marshes and river
- securing the water resource for drinking water, irrigation, livestock, fishing and other services
- Navigability optimisation for the Canal.

Project time frame and budget

Start date: 1 June 2023.

Estimated duration: 180 months.

Budget: approx. USD 783 million (Capital expenditure of USD 530 and operation expenses of USD 253 million).

Activities and funding mechanism

This project is developed under a PPP scheme with a solicited proposal. It is financed with contributions from the private party (equity and debt) that are paid back through public resources in accordance with the construction of the functional units and the fulfilment of indicators related to operation and maintenance established in the contract. It includes fourteen functional units (UF):

- **UF0:** Road access to the Calamar complex and road and dredging maintenance.
- **UF1:** River diversion for the lock construction in Calamar.
- **UF2:** Sheet pile installation in Calamar.
- **UF3:** Construction of Calamar set of locks.
- **UF4:** Calamar operation building complex, administration building and store.
- **UF5:** Flow control gate and fish passage of Calamar complex.
- **UF6:** River diversion for the Puerto Badel lock construction and road access to the Puerto Badel complex.
- **UF7:** Sheet pile installation in Puerto Badel.
- **UF8:** Construction of Puerto Badel set of locks, Puerto Badel complex control building, administration building and store.
- **UF9:** Complex F. Restoration of water bodies and construction of dikes.
- **UF10:** Complex G. Restoration of water bodies, fresh water supply to populations, protection dike and interceptor waterway construction, along with securing the area to avoid floods. New connection between Bays.
- **UF11:** Complex D. Construction of dikes, landfills, dams, waterways, new connection between marshes and road.
- **UF12:** Complex A, B and E. Construction of dikes, landfills and waterways and inlet and outlet connection of marshes.
- **UF13:** Protection of the Calamar population, flood protection wall and levee in the municipality of Calamar.
- **UF14:** Shoreline protection at critical points and shoreline scour protection structures.

Building a bulk supply point in a flood-prone area in Accra, Ghana

The building of a bulk supply point in a flood-prone area in the central business district of Accra (Ghana) is a success case of **reacting** to an emergency and increasing **preparedness.** It has increased energy supply and strengthened energy infrastructure resilience to flooding, achieved through international co-operation, technology adoption and capacity building.

P	R	R

Location and background information

Flooding stands out as one of the most common natural disasters in Ghana, mainly due to the country's relatively flat terrain. This topographical characteristic facilitates the accumulation of water, particularly during heavy rainfall events. Accra is particularly susceptible to flooding, given its low-lying nature and inadequate drainage infrastructure.

Accra Central, the bustling business district and capital of Ghana, is the primary load centre for the city. However, it has encountered several challenges with its electricity supply infrastructure, from high losses and inefficiencies to overload, and limited land for additional infrastructure. Frequent flooding has exacerbated these issues and highlighted the need for building a secure and natural disaster resilient power supply. As a result, the Ghana Grid Company (GRIDCo) proceeded to construct a Bulk Supply Point (BSP), completed in 2018 and financed by JICA (Japan International Cooperation Agency), which was designed in such a way as to both continue operations during flooding and enhance the quality and quantity of power supply to consumers across Ghana.

Main challenges to be addressed

In Ghana, the demand for electricity has been rising steadily following strong economic growth. However, this surge in demand has led to electricity shortages, particularly in urban areas like the metropolitan area and major cities. In Accra, the capital city, there has been a delay in expanding the electricity transmission and distribution network to keep pace with the rapidly growing demand. Addressing power losses in transmission and distribution has become urgent, especially as these losses increase with the expansion of electricity supply.

Accra's Central Business District (CBD) stands out as the primary hub for electricity demand in the region. However, the area has faced various power supply challenges. Poor bus voltage has resulted in low-quality electricity supply, while high losses during transmission and distribution have been observed. Frequent power outages, exacerbated by nationwide shortages, have further strained the electricity supply in the CBD. Additionally, the transmission transfer capacity has been insufficient, with transformers operating at 120% of their capacity during peak periods.

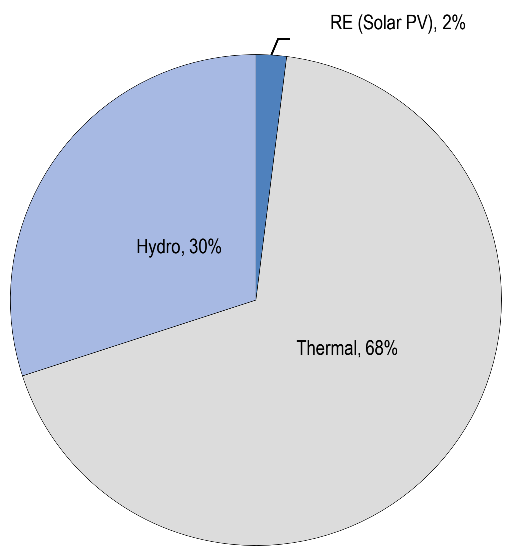
Moreover, Accra's densely developed urban landscape presents limitations in finding suitable locations for new electricity facilities. The available land for such infrastructure is relatively small, and the only viable option lies in a flood-prone area of the city. This presents a significant obstacle to expanding and improving the electricity infrastructure in Accra, as construction in flood-prone areas carries heightened risks and challenges.

Compounding these challenges is the district's susceptibility to flooding, as it lies in a flood-prone area of Accra, necessitating resilient infrastructure solutions to mitigate potential risks and ensure uninterrupted power supply to this critical economic hub.

Project description and assessment

In Ghana, the Grid Company, also known as GRIDCo, plays a crucial role in country's power system. As the system operator, GRIDCo is responsible for making critical decisions regarding which generators should contribute to the national grid and how power should be allocated among various loads. GRIDCo operations span across four voltage levels, including 69 kV, 161 kV, 225 kV, and 330 kV, catering to the diverse energy needs of the nation. The system peak demand stands at 3 558 megawatts (as of April 2023), with an installed generation capacity of 5 366 megawatts, with renewables such as hydro accounting for 30%, and solar 2%, and thermal fuel, primarily natural gas, making up the remaining 68% (Figure.3.2).

Figure.3.2. Mix of installed capacity for power generation by typology (% over total), Ghana, 2021



Note: RE = renewable energies (solar Photovoltaic)
Source: Authors' elaboration based on "Building Power Transmission Projects that are Resilient to Natural Disasters, Accra Central Bulk Supply Point as a Resilient Infrastructure", presentation by Kassim Abubakar, Principal Power System Planning Engineer, Ghana Grid Company Limited (GRIDCo) at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023. Based on IRENA statistics.

Despite the efforts to meet the growing electricity demands, the country encountered significant challenges in supplying power to the central business district of the capital city. This area, serving as a vital load centre, hosts numerous businesses, commercial establishments, light industries and administrative buildings. The issues faced included poor voltage quality, resulting in subpar power supply to consumers, as well as high distribution losses, frequent outages, and limited transmission and distribution capacity to ensure reliable electricity supply.

To address these challenges, GRIDCo identified the need to implement a new transmission facility to enhance the quality of power supply to consumers in the central business district. However, this presented several obstacles. First, the area was densely populated with limited available land for constructing large-scale infrastructure. Additionally, the geographical terrain posed challenges, as the neighbourhood was situated in a flat, flood-prone area.

The Accra Central Substation, designated to serve this area, was intended to act as a receptacle for stormwater during heavy rains, gradually receding into the nearby lagoon and eventually flowing into the sea. To address the electricity supply challenges in Accra, a Bulk Supply Point (BSP) construction project was initiated. The project's design and bidding phases commenced in 2015, followed by construction starting in 2016 and completion in 2018. The Accra Central BSP was conceptualised as a Gas Insulated Switchgear (GIS) station with a capacity of 375 MVA and operating at 161/34.5 kV, with provisions for expansion up to 500 MVA. Its primary objective was to bolster the power supply to the Central Business District (CBD) of Accra. To address the escalating demand in the CBD, the BSP aimed to minimise transmission losses and enhance the reliability of electricity supply by reducing outages and enhancing operational flexibility.

The site that was identified for the BSP was in a flood-prone area and was selected due to its availability and cost-effectiveness. Consequently, a crucial aspect of the project was to meticulously plan and design a facility that could withstand flooding, ensuring resilience against natural disasters. However, haphazard developments and inadequate drainage systems in a densely populated area led to blockages and the inefficient utilisation of existing infrastructure. Consequently, significant flooding in the neighbourhood often exacerbated the challenges faced by the transmission facility.

The design of the substation incorporated automatic submersible pumps to mitigate the impact of flooding. This feature activates whenever the nearby river floods, ensuring continuous power supply even during flood events. The effectiveness of this design was demonstrated during two major flooding incidents in 2020 and 2022, where the submersible pumps successfully maintained power supply without any interruptions despite the flooding.

In terms of construction methodology, special techniques were employed to minimise disruptions to economic activities in the busy business district of Accra where the substation was located. Specifically, a method involving drilling under roads and buildings was utilised to bury cables and extend high-voltage lines to the substation. This approach allowed for the completion of construction without significant disruption to commercial and business activities in the neighbourhood.

Overall, the incorporation of innovative design features and construction methodologies ensured the resilience and operational efficiency of the substation, even in challenging environmental conditions such as flooding. These measures enabled uninterrupted power supply to the central business district of Accra, contributing to the continued functioning of businesses and commercial activities in the area.

The duration of power outages has been notably reduced by approximately 45% compared to figures recorded in 2013. This improvement in outage duration demonstrates the enhanced reliability and stability of the power supply system. Furthermore, significant progress has been made in terms of transmission capacity, with the commissioning of a station capable of providing an additional 375 MVA of capacity. This increase in transmission capacity has contributed to meeting the growing electricity demand more effectively.

Table 3.2. Overview of project objectives and impact, building of a bulk-power station in a flood-prone area, Accra, Ghana, 2024

Project objectives	Impact
Improve quality of power supply and increase reliability of supply (reduce outages) Increase industrialisation and welfare of citizens.	The quality of power supply has improved significantly. Bus voltages at Accra Central are within ±5 of 34.5 kV nominal distribution bus voltage. The stability of power supply to CBD has been achieved (outage hours reduce by 95% compared to 2013 figures)
Increase transmission and distribution transfer capacity.	The transmission and distribution capacity has increased by 375 MVA, this is helping meet existing and future demand requirements.
Reduce transmission and distribution losses.	Technical losses in the transmission and distribution losses have reduced significantly.
Reduce Network Congestion (overloading)	Overloading on Achimota, Mallam BSP Transformers has been eliminated, transformers loaded around 60% of capacity now.

Source: "Building Power Transmission Projects that are Resilient to Natural Disasters, Accra Central Bulk Supply Point as a Resilient Infrastructure", presentation by Kassim Abubakar, Principal Power System Planning Engineer, Ghana Grid Company Limited (GRIDCo) at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place 18-19 April 2023.

Moreover, there has been a substantial reduction in technical losses within the power distribution system. Previously, technical losses were exacerbated by overloaded transmission and medium voltage distribution lines, leading to inefficiencies in power transmission. By addressing these issues and optimising the distribution network, technical losses have been significantly mitigated. For instance, the substation serving the neighbourhood, previously operating at an overloaded capacity of 120%, now maintains an average loading of 60% during peak periods.

Good practices and success factors

The project increased power supply capacity while the impact of flooding was minimal. The application of appropriate technology made it possible to scale-up electricity supply capacity and a new BSP construction within the available site remained operational in conditions of severe flooding. In particular:

- The quality of power supply has improved significantly. Bus voltages at Accra Central are within ±5 of 34.5kV as planned.
- The stability of power supply has been achieved with annual outage hours decreased significantly by 95% compared to 2013.
- The transmission and distribution capacity has increased by 375 MVA, which meets current and future demand. Technical losses in the transmission and distribution have reduced significantly, and overloading of other BSP transformers has been eliminated.
- Two major floods occurred (2020 and 2022) since the construction completed, neither of which resulted in any disruption to the facility and there was no interruption in power supply.

Several factors contributed to the successful implementation of this project, chief among them:

- **International collaboration, technology transfer and financial support.** The project was implemented by JICA under a grant agreement between JICA and the government of Ghana, with strong collaboration among GRIDco, the Electricity Company of Ghana and other stakeholders. The funding from the Japanese government, amounting to a grant aid of JPY 4.2 billion (approx. USD 38.5 million) facilitated through JICA, was instrumental in the project execution.
- Aligned with Ghana's national development policies and the long-term plan to increase electricity supply capacity, the government provided crucial support for the project, facilitating its smooth implementation through political decisions, certification, and granting of permits and land.
- Technology transfer was integral to the project's success, alongside well-planned operation and maintenance strategies executed by a team of well-trained and skilled staff. Thorough understanding of flood risks and meticulous project planning were pivotal to ensure effective mitigation strategies. The construction of the facility was carried out by a joint venture consisting of Mitsubishi Corporation, a Japanese trading house, Hitachi Plant Construction, a Japanese plant construction company, Yurtec, a Japanese electricity facility and engineering company and Yachiyo, an engineering company acting as the supervising consultant. Leveraging on their superior technology, diverse experience and project management capabilities, these companies played a pivotal role in the successful execution of the project. The collaboration among private providers and the construction company involved also contributed to the success of the project implementation. The project was implemented with significant support from the Ghanaian government through various agencies including the Ministry of Energy, the Ministry of Finance, the Energy Commission, the Electricity Company of Ghana, Ghana Railway, Ghana Water, Accra Metropolitan Assembly, and the Department of Urban Roads. With their collaboration, the project commenced and the construction of the substation was completed on time.
- **Innovative technologies and equipment**. Cutting-edge technology was employed for advanced monitoring, real-time data analytics and predictive capabilities, ensuring efficient operation and

maintenance. Advanced technologies were also integrated to enable operations with minimal disruption during maintenance activities. Notable technologies and equipment utilised include:

  - Six automated submersible pumps, which were installed to drain water during rains, mitigating the risk of flooding in the area.
  - Cables from the terminal tower were brought into the substation via underground cables using thrust boring techniques under drains and roads, minimising disruptions to vehicular traffic and water flow.
  - A concrete fire-resistant wall was incorporated into the BSP to prevent the spread of fire into or from the substation and its surroundings.
  - The Accra Central BSP features transformers equipped with acoustic noise abatement systems, effectively mitigating noise pollution in the neighbouring areas.
  - Innovative approaches such as the use of submersible pumps in cable culverts, GIS, and control buildings ensured construction continuity during flooding. Sheet piling techniques were also employed to prevent soil collapse in areas with high water content, facilitating timely construction completion without major delays.

- **Maintenance and capacity building.**
  - The operation and maintenance phase is managed by a team of well-trained and skilled staff, ensuring the facility's efficient and reliable operation.
  - Regular quality and safety compliance meetings were held during project implementation to ensure quality and zero accidents during construction (no accidents occurred during the implementation of this project).
  - Regular joint safety meetings between ECG and GRIDCo continue to enhance operational safety and efficiency, fostering a culture of co-operation and continuous improvement.

Increasing connectivity and preserving the environment through sustainable highways in India

The cases of the Delhi Mumbai Expressway, Raipur Visakhapatnam Expressway and the Bangalore Kadapa Vijayawada Expressway exemplify India's approach to infrastructure development. India follows a holistic approach which considers the overall socio-economic impact of infrastructure projects. India prioritises environmental preservation and innovation to increase connectivity. By developing and adopting broad national principles for infrastructure development, India has managed to innovate in infrastructure development while prioritising environmental sustainability and efficiency.

P	R	R

Location and background information

India is prone to severe natural disasters, including earthquakes, floods and various other hazards. The country's susceptibility to earthquakes is particularly noteworthy, with its land divided into different Seismic Zones ranging from Zone-II to Zone-V based on the severity of ground shaking. Zones IV and V, classified as the most severe, cover significant portions of the country, accounting for 14.4% and 11.3% of the land area, respectively. Measures to enhance infrastructure resilience to natural disasters are a top priority for India.

Given India's vast land area, growing megacities and increasing road traffic, the nationwide construction of a highway network is a crucial component of the country's development agenda. This endeavor is challenged by the high risk of earthquakes and other natural disasters, underscoring the urgent need to ensure the resilience of infrastructure to such hazards.

Main challenges to be addressed

India's massive effort of building a nationwide highway requires addressing multiple challenges in the various stages of the infrastructure project, spanning planning, construction and operation and maintenance phases, each demanding meticulous attention and strategic decisions.

During the planning phase, a comprehensive study of the area's geology, topography and hydrology is imperative to identify potential hazards and vulnerabilities. This entails assessing risks associated with landslides, flooding or earthquakes and strategically avoiding areas prone to such natural phenomena. By conducting detailed assessments, project planners can make informed decisions to mitigate risks and ensure the long-term resilience of infrastructure projects.

In the construction phase, selecting appropriate technologies is a critical challenge. It involves identifying and implementing technologies that not only meet project requirements but also address specific challenges posed by the project's location and environmental conditions. This necessitates thorough research and evaluation to determine the most suitable technological solutions that enhance the durability, safety and efficiency of infrastructure construction.

During the operation and maintenance phase, ensuring continuous operation under severe conditions and facilitating swift disaster response are paramount challenges. Infrastructure must withstand various environmental stresses and unforeseen events while maintaining optimal functionality. Establishing robust maintenance protocols and response mechanisms is essential to address potential disruptions promptly and effectively, minimising downtime and ensuring the reliability of critical infrastructure systems.

Overall, addressing challenges at each stage of infrastructure projects requires a multidisciplinary approach, incorporating thorough planning, innovative technology integration and proactive maintenance strategies. By strategically managing risks and implementing resilient solutions, infrastructure stakeholders can enhance project resilience and mitigate the impact of natural hazards on infrastructure performance and longevity.

Project description and assessment

The Government of India recognises transport roads and highways as crucial assets for the nation's development, emphasising the necessity for their construction, preservation and adequate maintenance. The Ministry of Road Transport and Highways of India is in charge of the national transportation policy which clarifies the overarching principles aimed at enhancing the life cycle of highways, thereby ensuring a comprehensive approach across all stages, from conceptualisation to maintenance.

These principles encompass various aspects such as design, engineering, construction, and maintenance, with the aim of fostering an end-to-end strategy for the development and upkeep of transport roads and highways. The Ministry of Road Transport and Highways mandates that these principles be applied uniformly across all interventions in transport road and highway projects, taking into account their unique characteristics and requirements.

In the planning phase, the key principles followed by India include:

- Conducting detailed studies on topology, geography and hydrology is essential to identify potential hazards and vulnerabilities in the area.
- It is imperative to avoid areas prone to landslides, flooding or earthquakes during the planning phase.

- Utilising advanced technologies for collecting site data is crucial in the project planning phase. This includes Topographical Surveys, Sub-surface Mapping, Traffic Monitoring and Verification of Land Condition.
- Components and engineering techniques are incorporated to minimise the impact of earthquakes and landslides. This involves adopting measures such as embankments, structure foundations and reinforced earth walls designed with seismic considerations.
- Structures with a design life of 100 years are designed for the Design Basis Earthquake (DBE), which accounts for moderate earthquakes that may occur more frequently. For example, bridges should be able to withstand minor structural damage.
- Structures with a design life of more than 100 years are also designed for the DBE and are checked for the Maximum Considered Earthquake (MCE), which accounts for a large earthquake that may occur once. Bridges may sustain significant structural damage but should not collapse, with bridge components expected to remain elastic.
- Various measures such as subsurface/surface drainage, retaining walls, slope flattening, buttresses, rockfall fencing/netting, and soil nailing/rock bolting are implemented to protect slopes.

In the disaster management plan and in the operation and maintenance phase, the following principles are adopted:

- Establishing a disaster management plan is crucial during the operation and maintenance phase. This plan outlines action plans, including emergency response measures such as evacuation routes and procedures, as well as communication strategies and guidelines.
- The implementation of an Automatic Traffic Management System (ATMS), including variable message signs, helps inform users about facilities along highways and ensures a quick response during emergencies.

In addition, India's road development policy clearly mandates that each action should be conducive to achieving the Sustainable Development Goals (SDGs); in particular, it includes the following principles:

- Implementing measures such as animal underpasses, overpasses and other devices helps mitigate the impact on wildlife.
- Planting trees along highways contributes to making them environmentally friendly.
- Considering the connectivity of highways between economically important cities and tribal and aspirational districts is essential to ensure holistic development and contribute to the Sustainable Development Goals (SDGs).

Good practices and success factors

During the preparatory work for the 2024 edition of this *Compendium of Good Practices on Quality Infrastructure*, India presented three case studies:

- Delhi Mumbai Expressway
- Raipur Visakhapatnam Expressway
- Bangalore Kadapa Vijayawada

The three cases exemplify India's approach to competitiveness-related infrastructure development, which aims at balancing efficiency with environmental preservation. In particular, the three cases are guided by the following objectives:

- **Strategic life cycle approach.** Adopting a life cycle approach strategy from the outset to ensure infrastructure resilience throughout its lifespan.

- **Detailed studies at the planning stage.** Conducting comprehensive studies at the planning stage to enhance resilience to natural disasters, enabling proactive measures to be integrated into project design.
- **Deployment of appropriate technologies.** Utilising appropriate technologies to construct structures capable of withstanding external forces during disaster scenarios, thereby enhancing overall resilience.
- **Prioritising resilience and capturing positive spillover effects.** The projects take a holistic approach and recognise the role of improved infrastructure resilience on broader socio-economic development opportunities.
- **Strong support from government leadership** for the adoption of innovative principles in project implementation. This is provided through direct orientation and guidance to ensure the application of the principles and their effective integration into project planning and execution processes.

The three projects share as a common feature the introduction of innovative approaches, often pioneering the implementation of these solutions in emerging economies in Asia, notably in the following areas:

- **Introduction of innovative solutions** on three highways, marking the first use of such approaches in Asia. These highways are intended to serve as pioneers, setting a precedent for future infrastructure projects in the region.
- **Implementation of innovative contracts** for engineering and management specifically designed to address challenges posed by earthquakes, floods and other natural disasters while ensuring adherence to project completion timelines. These contracts will incorporate unique provisions and strategies tailored to effectively manage and mitigate the risks associated with natural disasters, ensuring the timely completion of the projects despite potential disruptions.
- **Focus on territorial inclusion**, through the establishment of vital connections between large cities and communities, enhancing accessibility and promoting socio-economic development. The highways will play a crucial role in fostering connectivity and facilitating the movement of goods and people between urban centres and surrounding communities, thereby stimulating economic growth and regional development.
- **Focus on user convenience**, ensuring that the highways are designed and operated with the needs and preferences of users in mind. Attention will be given to user-centric design elements and operational practices aimed at enhancing safety, comfort and overall satisfaction for motorists and other road users.
- **Focus on environmental sustainability and implementation of measures to protect wildlife** along the highways, minimising the impact of infrastructure development on local ecosystems. Specialised measures and mitigation strategies will be employed to mitigate the environmental impact of the highways, including wildlife crossings, habitat restoration initiatives, and ecological monitoring programmes.

The following paragraphs describe in more detail the application of the abovementioned principles to each of the three specific projects.

- **The Delhi Mumbai Expressway** (Length: 1 386 km and Capital Cost: INR 101 420 Cr) is an example of India's commitment to bridge infrastructure gaps prioritising environmental sustainability, user convenience and innovative engineering solutions. It serves as the main 8-lane access-controlled greenfield expressway, linking India's national capital of Delhi with the financial capital of Mumbai. Notably, the operational section from Delhi to Dausa to Lalsot spanning 247 km commenced operations in February 2023, with a targeted completion date set for 2025. The application of the principles mentioned above has resulted in the following outcomes:
    - **Reduced construction time.** The project is on track to achieve completion within an unprecedented timeframe of 6 years from conceptualisation to execution, setting a new

benchmark for efficiency in large-scale highway projects. This timeframe significantly outpaces similar projects undertaken in other countries, demonstrating India's capability for rapid infrastructure development.

  - **Reduced travel distance and time**. Upon completion, the Delhi Mumbai Expressway is expected to reduce the distance between Delhi and Mumbai by 12%, resulting in a substantial reduction in travel time from the current 24 hours to just 12 hours. This enhancement in connectivity will greatly facilitate trade, commerce and passenger travel between the two major cities.
  - **Enhanced user convenience**. The project incorporates modern technology and infrastructure design to enhance user convenience and safety. Facilities for travellers have been planned with a view to increasing user experience. Additionally, real-time monitoring systems have been deployed to improve safety and efficiency, further enhancing the overall user experience.
  - **Innovative wildlife features**. The Delhi Mumbai Expressway introduces innovative features aimed at minimising its impact on wildlife. Notably, the project includes the conceptualisation and construction of animal underpasses and overpasses, a pioneering initiative in Asia and the second of its kind globally. Furthermore, the project boasts four iconic 8-lane tunnels, each exceeding 4 km in length, designed to reduce the impact on wildlife habitats and migration patterns.

- **The Raipur Visakhapatnam Expressway** (Length: 465 km and Capital Cost: INR 16513 Cr) serves as a 6-lane access-controlled greenfield corridor, connecting the capital of Chhattisgarh, Raipur, with the port city of Visakhapatnam. This project integrates innovative engineering solutions and wildlife-friendly infrastructure designs and sets a precedent for future infrastructure initiatives, aimed at balancing development with ecological preservation. This vital infrastructure project is slated for completion between 2024 and 2025, and the application of the principles mentioned above has led to:
  - **Pioneering highway configuration.** This expressway marks India's first highway traversing hilly terrain with a 6-lane configuration and a design speed of 100 kmph, showcasing innovative engineering solutions tailored to challenging topographical conditions.
  - **Enhanced connectivity.** By linking industrial cities with a major port city, the Raipur Visakhapatnam Expressway is poised to significantly reduce travel time between Raipur and Visakhapatnam from 14 hours to just 6 hours. This improved connectivity is expected to bolster trade, commerce and regional development.
  - **Innovative wildlife conservation measures.** The expressway incorporates innovative features aimed at mitigating its impact on wildlife and preserving natural habitats. Notably, the project includes the construction of six-lane tunnels, and animal underpasses and overpasses across the Sitanadi Sanctuary and other eco-sensitive areas. Specifically, the project features 13 elephant underpasses, 31 animal passes, and 31 monkey canopies dedicated to facilitating unencumbered wildlife movement. Additionally, the installation of smart cameras for wildlife monitoring enables the project team to closely track wildlife movement patterns and assess the project's impact on local ecosystems.
- **The Bangalore Kadapa Vijayawada Expressway** (Length: 342 km and Capital Costs: INR 13559 Cr) serves as a pivotal 6-lane access-controlled greenfield corridor, connecting Karnataka's state capital of Bangalore with the industrial areas of Andhra Pradesh, traversing through hinterland and underdeveloped regions. With a targeted completion date set between 2025 and 2026, the project prioritises environmental sustainability, longevity and efficient connectivity. The key principles mentioned above and applied in the project have led to:
  - **Longevity-focused design**. The project prioritises longevity by incorporating design elements that ensure resilience against natural elements. The finished road level is based on the

100-year high flood level (HFL) of nearby rivers, enhancing the infrastructure's ability to withstand flooding events. Additionally, the use of flexible pavement is adopted to provide a smoother ride experience and prolong the embankment's life span, contributing to the expressway's long-term durability.

- **Enhanced connectivity**. By linking IT clusters with industrial areas, the expressway is poised to significantly reduce travel time from 13 hours to just 7 hours, facilitating efficient movement of goods and commuters between key economic hubs in the region. This improved connectivity is expected to stimulate economic growth and enhance regional development.
- **Environmental conservation**: The alignment of the expressway is strategically planned to avoid wildlife sanctuaries, minimising disruption to local ecosystems and wildlife habitats. Furthermore, the project incorporates improved road geometry through viaducts connecting hilltops in the rolling terrain, mitigating environmental impact while ensuring efficient and safe transportation infrastructure.

Integrating resilience to natural disasters through the life cycle in the Mass Rapid Transport (MRT) Jakarta in Indonesia

The MRT Jakarta project aims at improving urban transport infrastructure in a highly densely populated area, that is vulnerable to natural disasters. The introduction of the MRT Jakarta system represents a significant step towards alleviating congestion and enhancing mobility within the metropolitan area. By providing a modern and efficient mass transit option, the MRT Jakarta aims to reduce reliance on private vehicles, alleviate traffic congestion and improve overall transportation efficiency. The project involves effective co-ordination and distribution of responsibilities between different stakeholders and relies on a comprehensive policy for resilience to natural disasters relying on smart use of data, technology and innovative design in facilities building and effective knowledge management.

P	R	R

Indonesia, and its capital city Jakarta, require heightened risk prevention measures

Indonesia, with its vast archipelago spanning across the equator, is highly vulnerable to a wide range of natural disasters due to its geographical location and geological characteristics. The country experiences frequent seismic activity, making it prone to earthquakes and subsequent tsunamis. Additionally, Indonesia lies within the Pacific Ring of Fire, a region known for its high volcanic activity, posing risks of volcanic eruptions that can result in widespread devastation.

Indonesia's climate vulnerability is exacerbated by the current climate crisis, which is increasing the frequency and impact of extreme weather events such as heavy rainfall, cyclones and floods. The combination of these factors amplifies the country's vulnerability to natural disasters, leading to significant socio-economic impacts and loss of life.

The densely populated urban areas, particularly in coastal regions, are at heightened risk, exacerbating the challenges of disaster preparedness and response. In addition to geological and hydro-meteorological hazards, Indonesia also grapples with environmental degradation and climate change impacts, further compounding its vulnerability to natural disasters.

Rising sea levels threaten coastal communities, while deforestation and land degradation exacerbate the risk of floods and landslides, particularly in mountainous regions. In the last two decades, Indonesia has faced several devastating natural disasters that have underscored the urgent need for enhanced natural disasters resilience measures. The 2004 Indian Ocean earthquake and tsunami, which originated off the coast of Sumatra, resulted in unprecedented destruction and claimed hundreds of thousands of lives. The 2018 Sulawesi earthquake and tsunami, followed by the 2018 Lombok earthquakes, highlighted the country's susceptibility to seismic events and the importance of effective disaster management strategies.

Addressing Indonesia's vulnerability to natural disasters requires a multi-faceted approach that encompasses robust disaster preparedness, early warning systems, infrastructure resilience and community engagement. Enhancing the resilience of infrastructure is imperative to support Indonesia's development efforts. Strengthening building codes, implementing land-use planning measures, and investing in resilient infrastructure are critical steps toward mitigating the impacts of disasters. Furthermore, enhancing public awareness and community resilience through education and capacity-building initiatives plays a crucial role in fostering a culture of preparedness and response at the grassroots level.

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

Improving urban transport and ensuring its resilience

The Jakarta metropolitan area faces multiple transportation related challenges. Chief among them are:

- **Chronic traffic congestion.** Viability is a significant challenge in the Jakarta metropolitan area. Persistent traffic congestion has long been a pressing issue, adversely impacting the region's economic productivity, environmental sustainability and overall quality of life. With the rapid urbanisation and population growth experienced in Jakarta, the demand for efficient and reliable transportation solutions has become increasingly urgent.
- **Overreliance on private vehicles.** Jakarta has long been characterised by high levels of car ownership and a culture of reliance on private vehicles for transportation. This overreliance on cars contributes to traffic congestion, air pollution and environmental degradation.
- **Limited public transportation options.** Prior to the introduction of the MRT Jakarta, the city's public transportation network consisted primarily of buses, which often operated in congested traffic conditions and were subject to delays.
- **Urban sprawl and population growth**. Jakarta's rapid urbanisation and population growth have led to increased demands on its transportation infrastructure. As the city continues to expand outward and its population grows, the need for reliable and efficient public transportation becomes more pressing.
- **Environmental sustainability**. Jakarta faces environmental challenges such as air pollution and greenhouse gas emissions, largely driven by the high volume of vehicles on its roads.

In the Jakarta metropolitan area, the risk of natural disasters, including heavy rainfall, floods, earthquakes, land subsidence and sea-level rise, is significant and has been growing. In particular, the main challenges to be addressed when it comes to improving urban transport, and that are taken into account in the MRT Jakarta project are:

- **Growing flooding risks.** One significant vulnerability of the Jakarta metropolitan area is its exposure to flooding, exacerbated by rapid urbanisation, land subsidence and inadequate drainage systems. The city is crisscrossed by 13 rivers and numerous canals, making it highly susceptible to inundation during periods of heavy rainfall. Additionally, Jakarta experiences tidal flooding due to its low-lying coastal location, with sea-level rise further exacerbating the risk of inundation.
- **Increasing seismic risks.** Jakarta's geology, characterised by soft soil, renders the city vulnerable to relatively high earthquake acceleration, hazard and risk during seismic events. Certain areas with

thick, loose to very loose sand deposit are highly susceptible to liquefaction under high earthquake acceleration. The presence of active fault lines near the city, including the notorious Sunda Megathrust Fault, poses significant threats to urban infrastructure and densely populated areas.

- **Growing environmental degradation.** In recent years, the Jakarta metropolitan area has also grappled with air pollution and environmental degradation, further exacerbating its vulnerability to natural disasters. Deforestation in surrounding areas has led to increased surface runoff and soil erosion, contributing to flooding and landslides, particularly during the rainy season.
- **Socio-economic inequalities and heightened risks for vulnerable communities.** Moreover, the socio-economic disparities within the Jakarta metropolitan area amplify the impacts of natural disasters on vulnerable communities, including illegal settlements and low-income neighbourhoods. These communities often lack access to adequate housing, infrastructure and disaster preparedness resources, increasing their susceptibility to displacement and socio-economic impacts during disaster events.

The Jakarta metropolitan area's vulnerability to natural disasters underscores the urgent need for comprehensive disaster risk reduction measures, including resilient urban planning, infrastructure upgrades, early warning systems and community engagement initiatives, to mitigate the impacts of future disasters and enhance the city's resilience.

The Mass Rapid Transit (MRT) Jakarta is a key component of Indonesia's efforts to improve urban transport

The Mass Rapid Transit (MRT) Jakarta, is a track-based urban transportation system designed to provide efficient and reliable mass transit services in the Jakarta metropolitan area. Current aspects of the MRT Jakarta project include the development of two primary lines: the North-South Line and the East-West Line. The North-South Phase 1, which spans from the city's northern suburbs to the central business district, was the first phase of the project to become operational. The commencement of operations on the North-South Line in March 2019 marked a significant milestone in Jakarta's efforts to improve its urban transportation infrastructure.

Recognising the critical need to address traffic congestion and enhance urban mobility, the implementation of the MRT Jakarta system represents a strategic investment in the region's transportation infrastructure. The MRT Jakarta project is designed to offer a viable alternative to traditional modes of transportation, such as cars and motorcycles, by providing a safe, reliable and efficient public transit option for residents and commuters.

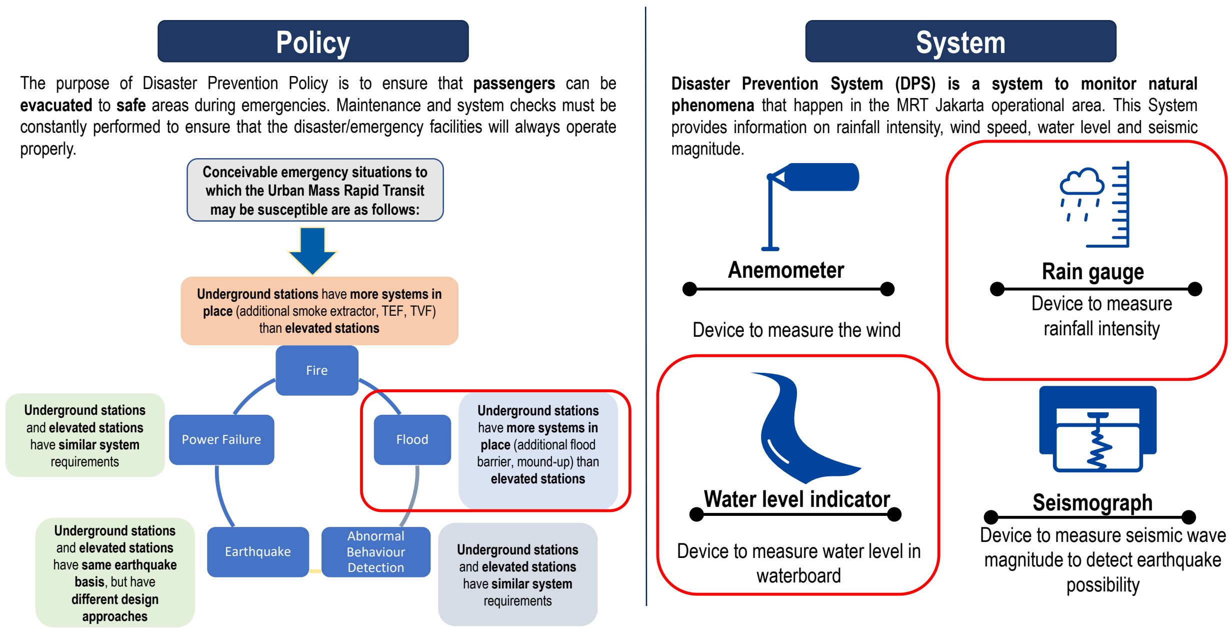
The project addresses multiple objectives, recognises the growing vulnerability to natural disasters and incorporates resilience as a guiding principle in all project phases from conception to building and implementation.

The MRT Jakarta project is aimed at:

- **Addressing the chronic traffic congestion** in the area; it is planned to accommodate the transportation needs of a growing urban population by reducing travel times and enhancing connectivity between key residential and commercial areas in the city.
- **Fostering environmental sustainability** by reducing reliance on fossil fuel-powered vehicles and encouraging the use of cleaner modes of transportation, improving air quality, and reducing carbon emissions in the city.
- **Minimising natural disasters' impact** through enhanced prevention capacities. It implements plans and facility designs aimed at minimising the anticipated impact of disasters in advance.
- **Ensuring effective reaction capacities** in the aftermath of a natural disasters. The project incorporates measures to ensure a seamless response and continuity of service provision in the event of a disaster.

The project counts with a disaster prevention policy and a disaster prevention system (DPS) (Figure 3.3).

Figure 3.3. MRT Jakarta's disaster prevention policy and system, Indonesia



Source: Authors' elaboration based on "Increasing MRT Jakarta Resiliency to Climate Disaster", presentation by PT MRT Jakarta, Indonesia at the 2nd preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Planning, Financing, and Building Infrastructure Resilient to Natural Disasters that took place on 7 September 2023.

Responsibility for the MRT Jakarta project is distributed among several key institutions, each playing a distinct role in its planning, implementation and operation. The central Government of Indonesia, holds overarching responsibility for setting policies, determines project funding schemes and ensures the project's alignment with national development objectives. Within the government, the Ministry of Transportation is a central player, overseeing the planning and development of urban transportation infrastructure projects, including the MRT Jakarta.

- A critical partner in the MRT Jakarta project is PT MRT Jakarta (Perseroda), a state-owned enterprise tasked with the construction, operation, maintenance and commercialisation of the MRT system and its TOD (Transit Oriented Development) operator. The government of Jakarta has delegated PT MRT Jakarta to serve as the sub-implementing agency for construction and be responsible for managing all aspects of the project's execution, from overseeing construction activities and co-ordinating with various construction-related stakeholders, to ensuring the system's safe and efficient operation. As the project's operator, PT MRT Jakarta also plays a vital role in managing day-to-day operations, including fare collection, maintenance of facilities and passenger services.
- The Government of Jakarta, specifically the Provincial Government of the Special Capital Region of Jakarta (DKI Jakarta), is another key stakeholder in the MRT Jakarta project, as the implementing agency. The DKI Jakarta provincial government develops the city master plan and collaborates with relevant stakeholders to address the city's needs and concerns. It is also accountable for the project's execution, such as land acquisition and resettlement, and for the supervision of MRT Jakarta. The national government, in particular the Directorate General of Railways at the Ministry of Transportation, as the executing agency and regulator of railway administrator, provides overall guidance, support, permits and approvals for implementing and operating the project. The close

collaboration between the national and provincial governments is essential for ensuring seamless co-ordination and alignment of priorities throughout the project life cycle.

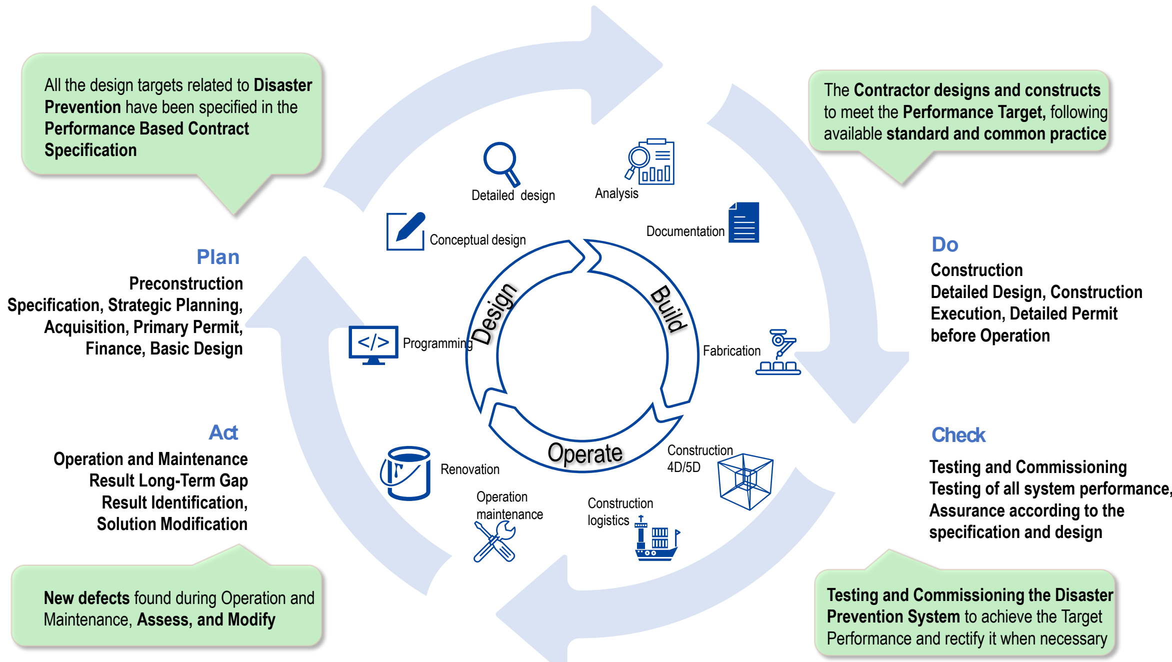
- Beyond government entities, the MRT Jakarta project also involves collaboration with various private sector partners, including engineering firms, construction contractors (including detail design consultants, sub-contractors and technology suppliers) and partnerships with other stakeholders. These private sector entities contribute specialised expertise, technical know-how and resources to the project, playing a crucial role in the successful delivery of key project milestones. Together, these diverse stakeholders form a collaborative ecosystem dedicated to realising the vision of a modern, efficient and sustainable urban transportation system for Jakarta.

Collaboration, smart use of data for risk assessment and technology stand out as key success factors of the MRT Jakarta

Several good practices can be identified in the MRT Jakarta project. In particular, they can be classified in six areas (spanning from design, targeted disasters' response mechanisms, risk assessment, reliance on digital technologies, collaboration and knowledge management):

- **Innovative and resilient facility design**
    - The initial phase of the MRT Jakarta project comprises both elevated and underground sections, each facing distinct challenges in terms of exposure to natural elements. While the elevated section is susceptible to heavy rainfall, the underground section faces flood risks. To address these challenges, specific improvements in facility design were implemented to mitigate associated risks.
    - For the elevated stations, rain screens were installed as part of an enhanced design strategy to minimise the impact of heavy rainfall on passengers waiting at the stations. These rain screens represent an upgrade from the original design, aimed at providing increased protection and comfort for passengers during adverse weather conditions.
    - In the underground stations, measures were taken to prevent floodwater from infiltrating the station premises. Mound up entrances, along with the installation of flood panels, were introduced to effectively mitigate the risk of flooding in underground stations. These countermeasures not only address flood risks but also offer protection against ground subsidence and potential sea level rise, ensuring the resilience of the underground infrastructure.
- **Passenger safety and disaster response mechanisms**
    - Central to the concept of disaster prevention is the assurance of passenger safety and the implementation of effective emergency response measures. Continuous maintenance and regular system checks are essential to ensure that all facilities operate optimally and can facilitate prompt evacuation procedures during emergencies.
    - The Disaster Prevention System (DPS) plays a crucial role in monitoring natural phenomena that could pose risks to the MRT Jakarta's operational areas (Figure 3.4). This system monitors various parameters such as rainfall intensity, wind speed, water levels and seismic activity. By continuously monitoring these factors, the DPS enables timely detection of potential hazards, allowing for proactive measures to be taken to safeguard passenger safety and ensure the smooth operation of the MRT system, even during adverse conditions.

Figure 3.4. Project life cycle for Disaster Prevention System: The MRT approach, Jakarta, Indonesia



Source: Authors' elaboration based on "Increasing MRT Jakarta Resiliency to Climate Disaster", presentation by PT MRT Jakarta, Indonesia at the 2nd preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Planning, Financing, and Building Infrastructure Resilient to Natural Disasters that took place on 7 September 2023.

- **Risk and impact assessment**. Continuous risk and impact assessment was conducted, identifying potential major disasters such as the potential increase in flood levels (heavy rainfall due to climate change, sea level rise and land subsidence), earthquakes, fire, terrorism and power failure. Recent trends and long-term predictions were analysed to inform decision making for improvement in disaster-resilient design. Precise data necessary for assessment was collaboratively obtained from relevant institutions, and digital technologies were used for the risk and impact assessment analysis.
- **Effective use of technology.** The selection and application of appropriate technologies were prioritised to effectively address disaster risks.
    - Disaster prevention targets were integrated into the performance-based contract specifications.
    - Initial designs of station facilities, such as rain screens, flood panels and mound-up entrances, were enhanced to improve resilience.
    - Waterways were modified by enlarging channels, creating absorption wells, and installing submersible slurry pumps to enhance drainage capabilities.
- **Collaboration.** Continuous collaboration with these institutions ensured a co-ordinated and comprehensive approach to disaster prevention.
    - Effective co-ordination with the Meteorology, Climatology and Geophysics Agency (BMKG) facilitated access to essential climate, meteorological, hydrological and seismic data. The installation of flood panels was based on hydrological and disaster studies against predicted flood levels under a 200-year rainfall return period. Updates in the hydrological study were based on additional considerations of heavy rainfalls due to climate change, sea level rises and land subsidence, conducted and co-ordinated with the Provincial Government of the Special Capital Region of Jakarta and other relevant organisations.

- MRT Jakarta (MRTJ) has played a pivotal role in co-ordinating with various governmental bodies and agencies to ensure the successful implementation of recommendations stemming from comprehensive hydrological and disaster studies. This co-ordination has involved close collaboration with the DKI Provincial Government and the Water Resources Agency (SDA).
- The DKI Provincial Government, as the local governing authority, has been instrumental in providing support and facilitating the integration of the MRT Jakarta project within the broader urban development framework of Jakarta. Their involvement has included land acquisition support, regulatory approvals and co-ordination with local communities to address any arising issues or concerns.
- The DKI Provincial Government has served as a key intermediary between MRTJ and the relevant government agencies, ensuring effective communication and alignment of priorities. Its role has been critical in facilitating inter-agency collaboration and streamlining administrative processes to expedite project implementation.
- Additionally, the Water Resources Agency (SDA) has played a vital role in providing expertise and guidance related to water management strategies and flood mitigation measures. Their input has been crucial in developing solutions to address flood risks and ensure the resilience of MRT Jakarta's infrastructure against natural disasters such as heavy rainfall and flooding.
- By working closely with these governmental bodies and agencies, MRTJ has been able to leverage their collective expertise and resources to implement comprehensive disaster prevention measures and enhance the overall resilience of the MRT Jakarta system. This collaborative approach underscores the importance of inter-agency co-ordination in addressing complex urban challenges and ensuring the long-term sustainability and natural disasters resilience of critical infrastructure projects.

- **Knowledge management.** MRT Jakarta implemented robust knowledge management practices to capture, disseminate and utilise lessons learned from firsthand experiences, particularly regarding resilience to natural disasters. Continuous knowledge management activities serve as a foundation for applying advanced technologies and building critical human resources and organisational knowledge to plan and manage resilient infrastructure projects and share knowledge with the community. Examples of effective knowledge management activities implemented in this project include:
  - Post-event retrospectives were conducted to discuss phase 1 project outcomes and lessons learned were compiled at the Internal Knowledge, Information, Education Center (KINETIC), as a basis for improvement on the following line project implementation.
  - Learning series books focusing on construction, and operation and maintenance were published to share experiences, insights and best practices.
  - MRT Jakarta also contributed to a study on flood management conducted by the Community of Metros Benchmarking Group (COMET) which compares and benchmarks practices among metros and shares learnings and best practices from various contexts and environments.

Investing in cutting edge technology and strategic preventive maintenance to build resilience in a cost-effective way in Japan

Japan has prioritised a focus on reducing vulnerabilities to natural disasters in a cost-effective way by increasing preparedness, for instance, through strategic preventive maintenance and the use of cutting-edge technology. The country has an integrated approach which levers on the regulatory framework to provide incentives for innovation and prevention measures as well as to clarify responsibilities for actions to be implemented to ensure prevention and reaction capacities operate in an effective and cost-saving way.

Location and background information

Japan's geographical location places it at significant risk of natural disasters, making it highly exposed to various catastrophic events.

Situated in the Circum-Pacific Mobile Belt, Japan experiences frequent seismic and volcanic activities, as the region is known for its tectonic instability. This geological setting contributes to the country's susceptibility to earthquakes, with Japan being one of the most seismically active areas in the world. Approximately 18.5% of the world's earthquakes of magnitude 6 or greater occurred in Japan between 2004 and 2013, often accompanied by high-risk tsunamis (Cabinet Office Government of Japan, 2015[2]). Additionally, the presence of numerous active volcanoes further amplifies the risk of volcanic eruptions, adding to the nation's vulnerability to natural disasters.

The country's extensive coastline and mountainous terrain exacerbate its exposure to natural hazards. Japan's coastline stretches over thousands of kilometers, making it susceptible to typhoons, heavy rains and storm surges originating from the Pacific Ocean. These weather phenomena, exacerbated by climate change, can cause widespread flooding, landslides and infrastructure damage, particularly in densely populated coastal areas. Moreover, the mountainous landscape increases the risk of landslides and flash floods, especially during heavy rainfall and monsoon seasons, posing additional threats to communities residing in mountainous regions.

Furthermore, Japan's densely populated urban areas, coupled with its highly developed infrastructure network, heighten the impact of natural disasters (Cabinet Office Government of Japan, 2015[2]). The country's robust economy and advanced technological capabilities have led to extensive urbanisation and the construction of critical infrastructure, including transportation networks, buildings and industrial facilities. While this development has contributed to Japan's prosperity, it also means that any disruption caused by natural disasters can have far-reaching consequences, resulting in significant economic losses, human casualties and disruptions to essential services.

Overall, Japan's unique combination of geological, geographical and socio-economic factors renders it highly susceptible to a wide range of natural disasters, including earthquakes, volcanic eruptions, typhoons and landslides. In 2019 alone, the estimated damages caused by floods and landslides amounted to USD 16.2 billion, underscoring the substantial impact of these disasters on Japan's infrastructure and economy (MLIT, 2021[3]). The country's ongoing efforts to enhance disaster preparedness, early warning systems and infrastructure resilience are crucial in mitigating the impact of these hazards and ensuring the safety and resilience of its population and economy.

Main challenges to be addressed

Given Japan's unique geographical, topographical and meteorological conditions, it is essential to construct infrastructure with disaster prevention features, particularly to enhance seismic and water related natural disasters resilience. This involves implementing technical and design measures, such as those to address soft ground challenges, and conducting regular maintenance.

In the case of Japan, a significant concern is the ageing infrastructure that was originally developed during the high economic growth period in the 1960s. In 2021, around 32% of bridges in Japan were over 50 years old, and this is projected to increase to 57% by the year 2031 (MLIT, 2021[4]). Addressing these challenges is critical to ensuring the long-term durability, safety and effectiveness of the country's infrastructure.

Project description and assessment

Japan has a strategic and holistic approach to infrastructure planning, combined with high investments, which integrates resilience to natural disasters and growing climate risks, not only at the outset of the planning, but also throughout its life cycle, including during the development and management of project infrastructure.

A key emphasis is placed on strategic preventive maintenance. This involves prevention measures aimed at improving and maintaining infrastructure assets before deterioration leads to failure. This proactive approach aims to avoid or delay the extensive resources and machinery involved in costly reconstruction efforts (OECD, 2022[1]). By formulating a systematic repair plan, carrying out necessary repairs and assessing them regularly, infrastructure integrity is preserved, enhancing its resilience against disaster events and minimising economic disruptions. Timely maintenance reduces life-cycle costs by mitigating future maintenance and repair/update expenses. It requires the estimation and integration of necessary maintenance budgets into overall infrastructure planning.

The effective utilisation of advanced technology is critical to enabling and simplifying construction, inspection and maintenance work in challenging topographical conditions. This facilitates the maintenance of infrastructure and reduces overall life-cycle costs by circumventing the need for costly extensive reconstruction efforts. According to estimates by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan, the adoption of preventive maintenance measures could lead to savings of approximately 32% in infrastructure maintenance and upgrade costs over the next 30 years, as compared to reactive maintenance approaches (MLIT, 2018[5]). Beyond the broader socio-economic benefits of resilient infrastructure, these savings directly benefit the government and investors, providing additional fiscal space for the enhancement of existing infrastructure or the construction of new infrastructure in other areas.

In Japan, when it comes to monitoring for strategic preventive maintenance, emerging technologies are proactively used with a view to increase efficiency, effectiveness and safety. For example, the Mobile Mapping System (MMS) utilises high-density laser scanning and infrared cameras to detect damages and cracks down to the millimeter level. By creating detailed 3D models of road surfaces and tunnel walls, MMS enables accurate assessment of current conditions and prioritisation of maintenance tasks, contributing to efficient inspection and monitoring and prolonging infrastructure lifetime (OECD, 2022[1]; MLIT, 2023[6]).

Approximately 30% of Japan's land area is characterised by steep lands in mountainous regions, rendering it uninhabitable and leading to the development of densely built urban areas. These areas are prone to frequent floods and landslides triggered by heavy rainfall, exacerbated by the presence of steep and short rivers (Cabinet Office Government of Japan, 2015[2]). These topographical challenges pose safety risks in the inspection and maintenance of infrastructure. To mitigate these risks, Japan leverages advanced technologies for monitoring and early detection of failures.

For example, Tokyo Gate Bridge utilises approximately 50 fiber-optic sensors resilient against dust and thunderbolt to generate about 2 800 data points per second. This system enables continuous monitoring of the bridge's condition and early detection of potential failures. The data obtained inform maintenance teams of the precise nature of damages, facilitating prompt and effective responses. This approach has enhanced monitoring efficiency and reduced costs (MLIT, n.d.[7]).

The central government of Japan further promotes preventive maintenance through targeted subsidies, as outlined in the national land resilience policy. For example, the "Five-year Acceleration Measures for Disaster Prevention and Mitigation and National Land Resilience" initiative includes measures aimed at addressing severe wind and flood damage and large-scale earthquakes. This includes the development of disaster prevention infrastructure and projects focused on addressing ageing infrastructure through preventive maintenance shifts. The budget allocation covers both national and local infrastructure, with the central government providing inspection manuals and training programmes to support local governments in their maintenance efforts (Cabinet Office Government of Japan, 2015[2]).

The planning and integration of strategic preventive maintenance into overall planning processes and budgets is instrumental in ensuring operational continuity with consistently high operational standards. Japan proactively incorporates advanced technology for monitoring purposes, facilitating timely data acquisition necessary for emergency evacuation processes and the design and operation of disaster-resilient infrastructure. This not only enhances the resilience of individual infrastructure assets but also ensures the resilience of regions and surrounding industries through improved operational continuity. For instance, the utilisation of optical fiber sensors for bridges enables the detection of bridge mutations and distortions before and after earthquakes, facilitating swift responses to abnormalities and the rapid restoration of transport operations.

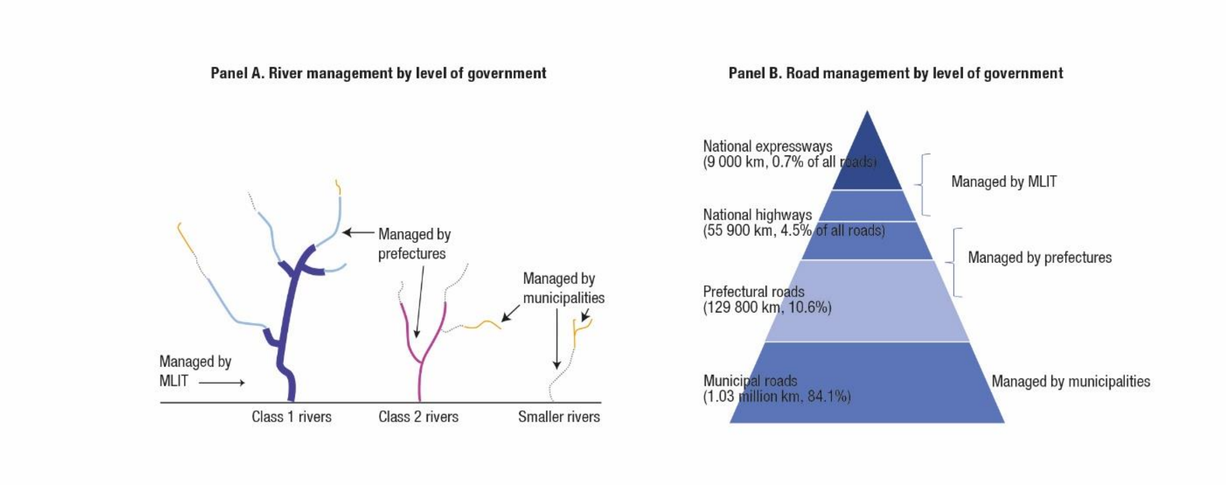
Japan actively promotes the deployment of cutting-edge technologies in other countries through initiatives like the Road Asset Management Platform (RAMP) established by the Japan International Cooperation Agency (JICA) in 2017. RAMP supports effective road asset management and offers capacity-building programmes on advanced technologies to developing countries. These programmes cover various areas such as bridge inspection using drones, AI (artificial intelligence)-based detection of damaged components, dynamic response intelligent monitoring systems, and slope measuring devices. RAMP collaborates with Japan's Cabinet Office-organized Infrastructure Maintenance, Renovation, and Management of Cross-ministerial Strategic Innovation Promotion Program to disseminate advanced technologies globally (JICA, n.d.[8]).

Good practices and success factors

Japan stands out as one of the leading promoters of quality infrastructure worldwide. It has promoted the G20 Quality Infrastructure Investment principles and it embeds resilience to natural disasters in its infrastructure investment policy. The use of strategic preventive maintenance and the capacity to innovate and utilise cutting edge technologies, including advanced and fast evolving digital solutions are distinctive features of the Japanese approach. In particular, the three following elements stand out as good practices:

- **A clear legal framework for strategic preventive maintenance**. Japan's national land resilience policy emphasises strategic preventive maintenance and outlines clear responsibilities among different levels of government, including the prefectures and municipalities (Figure 3.5). This ensures effective co-ordination and accountability in infrastructure resilience efforts.

Figure 3.5. Responsibilities for rivers and road management by level of government



Source: Authors' elaboration based on "Japanese method of enhancing resilience to natural disasters", presentation by Masahiko Murase, Director, International Cooperation and Engineering for Infrastructure, Ministry of Land, Infrastructure, Transport and Tourism, MLIT, Japan at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

- **A legal framework with clear provisions to invest and incentivise innovation and the use of advanced technology for prevention and re-building**. The development and deployment of cutting-edge technology plays a crucial role in enhancing the capacity to build infrastructure resilience and minimising damage costs. For instance, automatic evaluation and non-destructive inspection using Information and Communication Technology (ICT) significantly reduce costs and the need for skilled human resources. According to the New Technology Information System (NETIS), a database developed by MLIT to promote the deployment of new technologies in the private sector, 35 registered new technologies have, on average, reduced maintenance costs by 15% and time by 32% compared to conventional maintenance practices (MLIT, 2022[9]). These advancements not only contribute to more efficient maintenance operations but also bolster the overall resilience of infrastructure systems, ultimately enhancing their capacity to withstand and recover from adverse events.

  MLIT employs a comprehensive bidding system that evaluates positively construction companies incorporating advanced technology into their projects, compared to those who do not. Through direct financial support and tax incentives Japan incentivises innovation and encourages the deployment of cutting-edge technologies in infrastructure development to achieve resilience to natural disasters and climate-related risks (Nikkei XTECH, 2021[10]).
- **An emphasis on collaborative approaches in the areas of research and development, and innovation**. Collaborative efforts between government agencies, the private sector, academia and other stakeholders play a crucial role in advancing infrastructure resilience. In Japan, MLIT has established the Advanced Construction Technology Centre to facilitate research, development, and assessment of new technologies. This centre serves as a platform for disseminating knowledge and fostering collaboration among stakeholders, thereby driving innovation in infrastructure construction.

Increasing road network resilience through adapted standards and effective use of data in Mozambique

Mozambique has implemented a comprehensive national strategy to mitigate the impact of climate change and natural disasters on its transport network. The country has improved road standards, incorporating climate resilience considerations, and it has improved its early warning system and monitoring process through digital technologies.

P	R	R

The road network is highly vulnerable to natural disasters

Mozambique is among the world's most exposed countries to natural disasters and mounting risks associated to climate change. It faces significant challenges stemming from recurrent floods, droughts and cyclones, primarily due to its geographical features and hydrological characteristics. Sharing 9 of the 15 hydrographic basins in the South African Development Community (SADC) region and being downstream of 8 basins, Mozambique is particularly susceptible to flood risks. This hydrological connectivity exposes the country to the impacts of upstream activities, such as deforestation and land use changes, which can exacerbate flooding downstream.

Mozambique's hypsometric attributes, characterised by a significant portion of low-altitude terrain, contribute greatly to its flood vulnerability. Much of the country's landscape consists of plains formed over thousands of years by the floods of rivers and the deposition of alluvial material. Approximately 40% of Mozambique's total land area lies below an altitude of 200 meters, making it prone to inundation during periods of heavy rainfall or cyclonic activity. The catastrophic floods that struck Mozambique in January 2013 exemplify the profound impact of natural disasters on the country. These floods, which primarily affected the lower Limpopo valley and other southern regions, were the worst disaster since the floods of 2000. The devastating aftermath included 113 fatalities, the evacuation of approximately 172 600 people, and the destruction of nearly 89 000 hectares of cultivated land. The economic toll of the floods was also significant, with the Mozambique government estimating a substantial negative impact on economic growth.

Over the past two decades, the country has also been severely affected by cyclones, with 23 occurrences recorded since 2000. Recent years have witnessed a notable increase in cyclone activity, with significant events such as Cyclones Desmond, Idai and Kenneth in 2019, followed by Cyclones Ana, Dumaku and Gombe in 2022. The impact of these cyclones on Mozambique's infrastructure and communities underscores the urgent need for resilient measures to mitigate the devastating effects of such disasters.

Natural disasters are deeply affecting the functioning of the road transportation network in Mozambique, posing major economic challenges to the country and the overall region, as Mozambique serves as a gateway for several land-locked countries in the region.

Mozambique needs to address its transportation infrastructure vulnerability under a tight budget

Mozambique relies heavily on road infrastructure for the transportation of goods, particularly to ports, due to being a coastal country with landlocked neighbours.

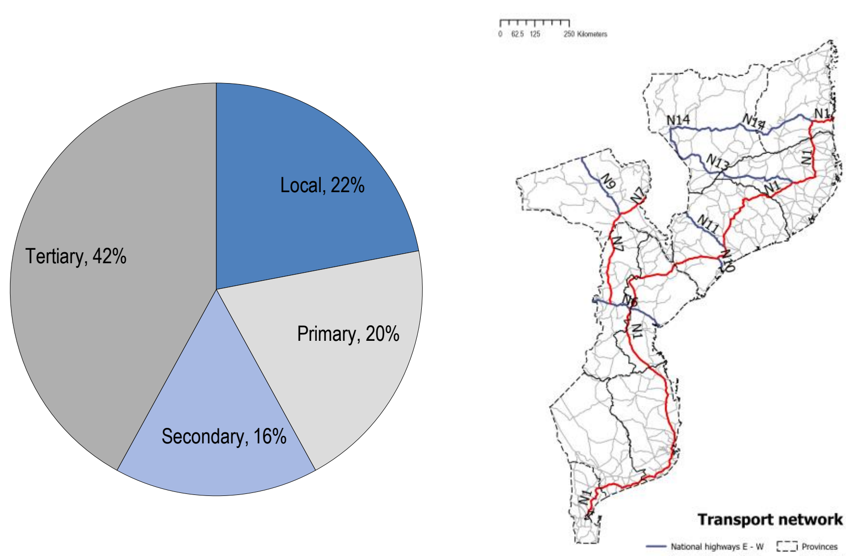
The country suffers from multiple vulnerabilities:

- **Climate change vulnerability and heightened risk of natural disasters**. The country faces various challenges such as floods, cyclones and varying rainfall patterns, leading to exposure and vulnerability of road networks, especially in coastal areas. Climate change is also introducing significant uncertainty. Road assets generally have service lives of several decades, therefore design parameters or the choice of materials need to be chosen in a way that can withstand future conditions.
- **Infrastructure vulnerability**. The vulnerability of Mozambique's road networks is exacerbated by various natural hazards, including floods and cyclones, as well as the country's exposure to fluctuating rainfall patterns. With few redundancies and prone to disruptions, the road network, especially the north-south links, is prone to disruptions caused by river floods and cyclones. These environmental factors pose significant risks to the stability and functionality of the road infrastructure, particularly in coastal regions, highlighting the urgent need for resilient planning and infrastructure management strategies. Furthermore, the ageing infrastructure presents challenges in adapting to the impacts of climate change, necessitating comprehensive assessments and interventions to enhance resilience and sustainability (Figure 3.6).
- **Budgetary constraints**. While efforts are underway to implement resilient measures, budgetary constraints pose challenges to the comprehensive enhancement of Mozambique's road infrastructure. Implementing resilient measures raises questions about economic feasibility, especially considering the extensive network of mostly unpaved roads which require preventive, reacting and rebuilding responses.

Figure 3.6. Classification of roads in Mozambique, 2023

Panel A. Share of roads by class

Panel B. Map of highway network



Source: Authors' elaboration based on "Increasing Infrastructure Resilience to Natural Disasters". Presentation by Cecilio Maria da Grachane, Engineer, Road Fund, Ministry of Public Works, Housing and Water, at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

To ensure resilience to natural disasters, the road network in Mozambique, aged between 50 and 60 years, relies heavily on traditional preventive measures such as building embankments. However, the onset of climate change is resulting in more intense rainfall and shifting weather patterns, rendering these measures increasingly inadequate. Particularly in the Limpopo lower basin, where most roads are constructed on embankments functioning as dikes, the impact of floods has been severe. At least 18 stretches of paved roads and bridges, including three sections of the main national highway, were damaged during recent flood events. Numerous villages were inundated, with some completely cut off and others accessible only by boat. The province's road network sustained extensive damage, with approximately 70% affected, equating to 2 200 kilometers of roads, 30 bridges and culverts, and 62 aqueducts.

To address the challenges posed by climate change and ensure the sustainability and resilience of the country's road network, Mozambique is pursuing a multifaceted approach:

- First, emphasis is placed on proper maintenance of existing infrastructure based on their anticipated risks, ensuring proactive measures are in place to mitigate potential damage.
- Second, efforts are directed towards enhancing connectivity options to accommodate natural disaster occurrences, providing alternative routes or transport modes during emergencies.
- Third, the country is proactively integrating climate adaptation strategies into ongoing infrastructure projects, layering resilience measures over existing work. In the context of climate change, provision of reliable accessibility depends upon effective planning for potential impacts of extreme events and building resilience in the road network accordingly.

Mozambique has strengthened its prevention and reaction capacity through the smart use of data, technology and infrastructure design

To address infrastructure vulnerabilities, Mozambique is implementing technical solutions such as adjusting road design standards and incorporating innovative engineering practices. These measures include modifying slopes and enhancing structural elements in bridges to withstand the effects of extreme weather events and ensure the long-term functionality and safety of the road network. In particular, Mozambique has:

- Introduced new national design and build specifications aimed at enhancing infrastructure resilience to extreme weather events. The new design standards for the National Road Network have been developed and implemented since 2019, incorporating climate resilience considerations.
- Conducted vulnerability assessments of existing roads through pilot projects, prioritising retrofitting and resilience enhancements.
- Introduced the testing of new technical solutions through pilot projects, exploring innovative approaches to strengthen infrastructure resilience in the face of climate change impacts.
- Strengthened its early warning system and the institutions which ensure its effective functioning. Among them it is worth noticing:
  - The National Meteorology Institute (INAM), which utilises satellite imagery, radar data and observations from a network of monitoring stations to produce meteorological warnings.
  - The Institute of Social Communication, which plays a crucial role in disseminating these alerts through its network of 70 community radios. Additionally, trained community brigades are mobilised to warn at-risk communities, guiding them to safety before the occurrence of extreme weather events.

Acknowledging the inherent uncertainties associated with climate change, Mozambique emphasises the importance of adaptive learning and continuous improvement in infrastructure planning and management. By monitoring and evaluating the effectiveness of resilience strategies over time, authorities can better understand evolving risks and refine response measures to ensure the long-term sustainability and functionality of the road network amidst changing environmental conditions.

Redundancy in road network and early warning systems are key pillars of the national resilience strategy

Mozambique has strengthened its capacity to monitor and measure the resilience of infrastructure to natural disasters. The integration of advanced technology, community engagement and effective data tracking systems enhances the country's ability to anticipate hazards, issue timely warnings, and implement proactive measures to safeguard critical road networks and protect the lives and livelihoods of its citizens. In particular, it is worth noting the actions implemented in the following fields:

- **Data Tracking System for Hazard Events and Impacts.** Mozambique employs a robust data tracking system that includes recording hazard events, localisation and impacts, allowing for the classification of road networks based on identified risks and impacts. This system enables authorities to categorise roads according to their vulnerability and define specific risk factors associated with each segment. Examples of road network classification include identifying roads with exposure to permanent exceptional risk, roads prone to flooding and damage due to insufficient drainage capacity, roads with high volumes of runoff leading to overtopping and road cutting, and roads experiencing erosion and poor excavation at bridge abutments. This information enables authorities to strategically allocate resources and deploy timely interventions to minimise disruptions and enhance the resilience of critical infrastructure.
- **Early Warning System.** Mozambique has implemented an early warning system that enables the country to track potential hazards, issue timely alerts and take proactive measures to minimise the impacts on people's lives and property. This system integrates new technology, infrastructure and community action to ensure effective communication and response. Key institutions in charge of ensuring the effective functioning of the national early warning system are:
- **Redundancy and resilience.** Mozambique recognises the importance of creating redundancy within its road network to ensure continuous connectivity and minimise disruptions in the event of infrastructure failures or natural disasters. By strategically planning alternative routes and improving interconnectivity, authorities aim to enhance the resilience of the road network and mitigate the socio-economic impacts of disruptions on local communities and regional trade.

In the context of Mozambique's interconnected hydrographic basins, it is imperative to consider **cross-border issues when developing infrastructure resilience to natural disasters**. The interconnected nature of hydrographic basins means that activities upstream can have significant downstream impacts, including the potential for increased flood risks and changes in water flow patterns. Therefore, effective co-ordination and collaboration with neighbouring countries is essential to address shared challenges and mitigate the transboundary impacts of natural disasters.

One key aspect of addressing cross-border issues is the need for information sharing and early warning systems that encompass multiple countries within the region. This includes sharing data on rainfall patterns, water levels and potential flood risks, as well as co-ordinating response efforts in the event of a natural disaster. By establishing collaborative mechanisms for information exchange, countries can better anticipate and prepare for disasters, reducing the potential for adverse impacts on infrastructure and communities across borders.

Furthermore, infrastructure resilience planning should take into account the interconnectedness of transport networks and trade routes between countries. Roads, bridges and other critical infrastructure often serve as lifelines for cross-border trade and transportation, making them particularly vulnerable to natural disasters. Therefore, efforts to enhance infrastructure resilience should consider not only the local impacts of disasters but also their potential effects on regional trade and connectivity.

In addition to physical infrastructure, cross-border collaboration is essential for addressing broader challenges related to disaster response and recovery. This includes co-ordinating efforts to provide humanitarian assistance, support affected populations and rebuild damaged infrastructure. By working together across borders, countries can leverage collective resources and expertise to enhance resilience and build back better in the aftermath of natural disasters. Overall, prioritising cross-border co-operation and co-ordination is essential for effectively addressing the interconnected challenges of infrastructure resilience in the context of Mozambique's interconnected hydrographic basins and shared borders with neighbouring countries.

United States: Fargo-Moorhead Flood Diversion Project

The implementation of the Fargo-Moorhead flood diversion project was driven by the urgent need to address the significant and recurring threat posed by flooding in the region. It represents a critical investment in the region's long-term resilience to flooding, aiming to safeguard lives, protect property and critical infrastructure, and promote sustainable development and economic prosperity in the area and its surrounding communities. By pooling together resources and expertise from multiple stakeholders (federal, state, local and private sector), the project was able to overcome financial and technical challenges and began construction in 2022. The project is the first flood management project in North America to use a PPP model and is expected to be operational by early 2027.

P	R	R

The Fargo-Moorehead metropolitan area is one of the most flood-prone regions in the United States

The United States is highly exposed to natural disaster risks due to its diverse geographical and climatic conditions:

- The country is susceptible to hurricanes along its Atlantic and Gulf coasts, with states like Florida, Louisiana and Texas particularly vulnerable. These powerful storms bring strong winds, heavy rainfall, storm surges and flooding, causing widespread damage to infrastructure, businesses and communities.
- The United States is prone to earthquakes, with seismic activity concentrated along the Pacific Coast, notably in California. Earthquakes can result in structural damage, landslides and tsunamis, posing significant risks to populated areas.
- The country experiences tornadoes, especially in the central region known as "Tornado Alley" where states like Oklahoma and Kansas face frequent tornado activity. These violent storms can devastate communities and cause loss of life, infrastructure disruption and property damage.

Within the United States, the Fargo-Moorhead metro area stands out due to its susceptibility to flooding and extreme weather events. The Fargo-Moorhead metro area comprises Cass County, North Dakota and Clay County, Minnesota, which includes the cities of Dilworth, Minnesota, West Fargo, North Dakota and numerous other towns and developments from which residents travel daily for work, education and regular activities. Situated in the northern section of the Red River the metro area is prone to flooding, particularly during the spring thaw and periods of heavy rainfall (North Dakota State University, 2009[11]).

Its vulnerability stems from a combination of factors, including its location in the northern section of the Red River, the flat topography of the surrounding area and the river's low gradient. Additionally, ice melting from southern regions contributes to ice jams along the river, exacerbating flood risks. Moreover, the region frequently experiences extreme precipitation events, a trend that has been intensifying since 1990. The Red River has exceeded the National Weather Service flood stage of 18 feet in 60 of the past 124 years (1902 through 2023), with seven of the top ten floods occurring in the last 30 years. A 500-year event would flood nearly the entire city of Fargo, a large portion of the city of Moorhead and several smaller communities in the area. Flooding occurs not only from the rivers but also from large rainfall events that overwhelm storm drainage systems. Average annual flood damages are estimated at approximately USD 238 million. Although emergency flood fights have been very successful, the area has a significant risk of catastrophic flooding (USACE, 2023[12]).

The Fargo-Moorhead flood diversion project aims at increasing preventive capacities and reducing flood vulnerability in the metro area

The project's key objectives are:

- **To limit damage to homes, businesses and the regional transportation network.** The flood events in the area require emergency measures such as constructing levees along large portions of the Red River in the effort to retain floodwaters to prevent widespread damage to properties and transportation infrastructure. Businesses, residents, Federal agencies, and local and state governments each contribute to the flood fight, rescue and clean-up efforts which take significant financial and human resources. By managing spring snow melt and summer stormwater, the project is expected to protect 245 000 residents from excess stormwater flows.
- **To establish permanent flood protection for the region and reduce the risk of catastrophic events.** The project aims at reducing the risk of catastrophic flooding in the Fargo-Moorhead metro area, protecting critical infrastructure and assets, and safeguarding the lives and property of residents and businesses in the region. By constructing a comprehensive flood diversion system, the project aims at redirecting floodwaters away from populated areas and channelling them safely downstream, thereby minimising the risk of damage and disruption caused by flooding.

The recurrent flooding poses significant challenges to local communities, leading to disruptions in daily life, damage to homes and businesses, and substantial economic losses. Additionally, the reliance on emergency measures to combat flooding underscores the vulnerability of the area and the necessity for long-term, sustainable flood management solutions. These issues highlight the urgent need for effective flood mitigation measures to protect lives, properties and critical infrastructure in the Fargo-Moorhead metropolitan area.

The project is a large-scale flood reduction and mitigation initiative

The Fargo-Moorhead flood diversion project is a large-scale flood mitigation and management initiative with a total cost of about USD 3 billion.

The project involves the construction of a comprehensive flood diversion system designed to protect the region from the recurring threat of catastrophic flooding along the Red River and its surrounding tributaries. The project components include:

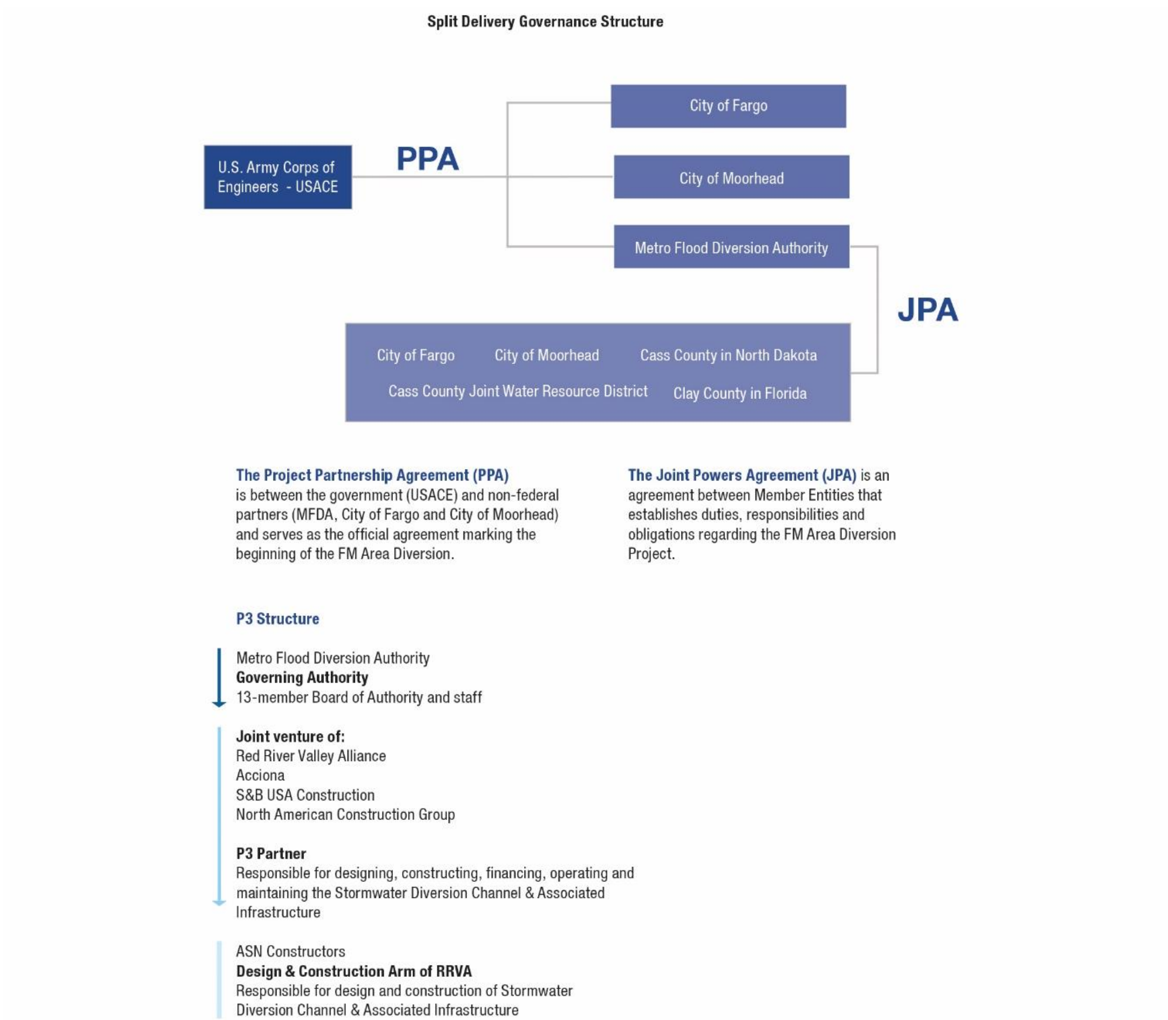
- **The diversion channel and transportation infrastructure** delivered through a public-private partnership (PPP). The primary component of the project is the construction of a 30-mile-long flood diversion channel along the Red River, which will serve to redirect floodwaters away from populated areas during periods of heightened flood risk. This diversion channel will be equipped with various control structures, such as gates and levees, to regulate the flow of water and minimise the risk of inundation in downstream communities.

  Since the construction of the diversion channel will disrupt the local road and rail network located along its 30-mile path, the project includes construction of new transportation elements including two pairs of interstate bridges, 12 county road bridges or crossings, 3 railroad bridges and a number of mixed-use trails along the channel that will be available for hiking after the project is completed.
- **Southern embankment with upstream water staging and storage** constructed by the United States Army Corps of Engineers (USACE). USACE is designing and constructing the 22-mile Southern Embankment and three large, gated control structures (USACE, 2023[12]).

- **In-town flood mitigation and stormwater management facilities** encompassing levees, floodwalls, stormwater lift stations, road enhancements, and grade raises in the cities of Fargo and Moorhead. These additional components of the project are strategically located to provide comprehensive flood protection to vulnerable areas within the Fargo-Moorhead metropolitan area and its surrounding environs.

The Fargo-Moorhead diversion project is a collaborative effort involving multiple stakeholders, including local, state and federal government agencies, as well as private sector partners and community organisations (Figure 3.7). USACE, as the lead agency responsible for the development of large flood management facilities in the United States, entered into a Project Partnership Agreement (PPA) with the local governments and the Fargo-Moorhead Metro Flood Diversion Authority (MFDA) to implement the project. MFDA contracted a private sector partner to implement the diversion channel and associated infrastructure. The project's development and implementation have been guided by extensive planning, engineering and environmental assessments to ensure its effectiveness, sustainability and compliance with regulatory requirements.

Figure 3.7. Project stakeholders and governance structure, Fargo-Moorhead project, United States



Note: PPA: Project Partnership Agreement. JPA: Joint Powers Agreement
Source: Authors' elaboration based on Fargo-Moorhead Metro Flood Diversion Authority (n.d.), FM Area Diversion Delivery Structure https://fmdiversion.gov/about/delivery/

Overall, the Fargo-Moorhead diversion project represents a critical investment in the region's long-term resilience to flooding, aiming to safeguard lives, protect property and critical infrastructure, and promote sustainable development and economic prosperity in the area and its surrounding communities.

Collaboration and co-ordination have been key to ensure project implementation and effectiveness

Among the several good practices of this project, the following two stand out: the effective collaboration and co-ordination across multiple stakeholders, which resulted in an effective project delivery strategy; and the community buy-in as reflected by the diverse funding and financing sources, with contributions of funding from federal, state, local, and capital markets for this capital-intensive project.

An innovative project delivery model was used that allowed the delivery of a large component of the project (the diversion channel and transportation infrastructure) to be outsourced to the private sector. The establishment of the MFDA by the local communities with its dedicated source of funding for flood management projects allowed MFDA to leverage its annual tax receipts and receive a loan that funded construction milestone payments to a private sector partner responsible for delivery of the diversion channel and the transportation infrastructure.

- **Stakeholder collaboration and co-ordination enabled by public-public and public-private partnerships**.
    - The communities of Fargo, ND and Moorhead, MN along with Cass County, ND, Clay County, MN, and the Cass County Joint Water Resources District established the Metro Flood Diversion Authority (MFDA) with the goal of reducing flood risk and damages for the stakeholder communities and counties by building and operating a flood diversion channel along the Red River.
    - MFDA and its members worked with USACE to develop the Fargo-Moorhead Metro Flood Risk Management Feasibility Study for the flood diversion channel project.
    - USACE and MFDA agreed to deliver the project as a "split delivery model" where USACE would retain the responsibility for the delivery of the Southern Embankment and associated infrastructure, MFDA would procure construction of the diversion channel as a PPP project and the cities of Fargo and Moorhead and local communities would spearhead the development and upgrade of the in-town flood mitigation infrastructure. MFDA selected the Red River Valley Alliance (RRVA), a PPP consortium to build the diversion channel and the associated infrastructure, including the transportation elements, under a long-term PPP contract. Under this contract RRVA will also operate the channel.
    - The project has been a high priority for local communities and organisations, cities and governments of the States of North Dakota and Minnesota as well as for USACE. Over time, the project expanded to encompass a network of over 50 organisations from both the public and private sectors. This diverse coalition included 20 utility companies and 30 federal, state, and local agencies, necessitating extensive co-ordination efforts.
    - To facilitate the project's implementation, 14 new pieces of legislation were enacted, along with the issuance of 200 permits containing over 2 000 conditions for monitoring purposes. Additionally, 70 memoranda of understanding/agreements were established among the participating entities (Build America Bureau, US Department of Transportation, 2023[13]).
    - The project's innovative approach allowed different components to be executed by distinct groups of partners, resulting in accelerated project delivery compared to traditional funding and financing methods (Metro Flood Diversion Authority, 2023[14]).
    - Collaboration between engineering and contracting teams has resulted in streamlined construction processes and the implementation of cutting-edge technologies, further reducing

costs. Overall, the mobilisation of the private sector fostered efficiency, innovation and cost reduction.

- Two federal agencies – the Environmental Protection Agency (EPA) and the US Department of Transportation's Build America Bureau played a pivotal role in providing low-cost and long-term financing to the project (Box 3.1). Federal government agencies' involvement in the project has been key in advancing the project implementation and overcoming key challenges related to project funding and financing.

Box 3.1. Federal long-term and low-cost project financing sources

Build America Bureau: DOT's lender for transportation projects

The Build America Bureau (the Bureau) was established in 2016 as part of the US Department of Transportation (USDOT) with the primary goal of facilitating transportation infrastructure investment in the United States. The Bureau was created to serve as a centralised hub for project finance in the US transportation sector. Its mandate encompasses a wide range of responsibilities including providing low-cost, long-term financing with flexible repayment terms to eligible projects, promoting innovative financing solutions, fostering public-private partnerships (PPPs), and accelerating the delivery of infrastructure projects across the country.

The Bureau also provides grants and technical assistance and financial expertise to federal, state and local government agencies, as well as private sector entities, seeking to develop infrastructure projects. The Bureau plays a crucial role in promoting best practices and knowledge sharing in infrastructure development. By disseminating information on successful projects, financing mechanisms and policy frameworks, the Bureau helps build capacity and foster collaboration among stakeholders, driving innovation and excellence in infrastructure development nationwide.

The Bureau provides project finance assistance via its three key programmes:

- **Transportation Infrastructure Finance and Innovation Act (TIFIA)**: this programme provides loans for surface transportation and public infrastructure.
- **Railroad rehabilitation and improvement financing (RRIF):** this programme provides loans for passenger, freight, and commuter rail and transit-oriented development.
- **Private activity bonds**: this programme provides allocations of private activity bond (PAB) authority to qualified surface transportation and transfer facilities that allow public-private partnership (PPP) projects to access lower cost ("tax-exempt") financing than the cost of a taxable bond.

Water Infrastructure Finance and Innovation Act (WIFIA) programme: EPA's lender for water projects

The WIFIA programme is a federal credit programme administered by EPA for eligible water and wastewater infrastructure projects. The WIFIA programme was modelled after the successful TIFIA programme administered by the Build America Bureau. The WIFIA programme's mission is to accelerate investment in the US water and wastewater infrastructure by providing long-term, low-cost financing with flexible repayment terms to creditworthy water and wastewater projects of national and regional significance.

The US Federal Government's lending through the TIFIA, RRIF and WIFIA programmes allows critical infrastructure projects to access long-term financing at affordable interest rates comparable to the US Treasury securities rates. The state and local governments can pledge their annual tax revenues as a repayment source for the loans, thus accelerating delivery of their infrastructure projects. US DOT also recognises the important role of the private sector in transportation infrastructure delivery. Both the

TIFIA and the Private Activity Bonds programmes, administered by the Build America Bureau, have also made a significant contribution to the development of the US PPP market by providing long-term financing at affordable rates for construction of large capital-intensive transportation projects.

Through its comprehensive approach to infrastructure investment, the Bureau has become a key driver of economic growth and prosperity, supporting job creation, enhancing connectivity and improving the overall resilience of the nation's infrastructure.

Table 3.3. The Build America Bureau in a nutshell

What does the Build America Bureau do?	
Financial assistance	**Technical assistance**
Flexible, low-cost, long-term credit assistance (loans, loan guarantees, and lines of credit) – USD 100 billion available for a wide range of projects; and tax-exempt bonds – USD 15 billion available for public-private partnerships.	Grants for project planning and development, community solutions and advisory services; and opportunities for training and education on the use of innovative project planning, financing and delivery techniques.
Major Build America Bureau programmes	
Name	**Details**
Transportation Infrastructure Finance and Innovation Act (TFIA) of 1998	Surface transportation and public infrastructure Airports can finance up to 33% of eligible project costs
Railroad rehabilitation and improvement financing (RRIF)	Passenger, freight, and commuter rail and transit-oriented development Finance up to 100% of eligible project costs
Private activity bonds	State/local governments issue tax-exempt bonds Private equity responsible for debt services Can be used alone or in combination with TFIA and RRIF
Key features of the Bureau's major programmes	
Highly customisable to meet borrower needs Borrowing of up to 33% of eligible project costs and up to 49% for rural, transit and TOD projects Long-term repayment period – up to 35 years Accrues interest when funds drawn Optional five-year deferral after completion No pre-payment penalty Also offer loan guarantees and lines of credit Low interest rate of 3.77% for 35-year loan as of 17/4/23	

Source: Authors' elaboration based on the presentation by Morteza Farajian, Executive Director, Build America Bureau, US Department of Transport at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

- **Community buy-in and diversification of funding and financing sources**
  - Diversifying funding and financing sources was imperative due to the substantial cost of the project, totaling approximately USD 3 billion, which exceeded the capacity of local public stakeholders to raise independently.
  - A sound assessment of the cost of inaction – for instance, the estimated damages caused by the floods in 1997 alone amounted to USD 3.5 billion – provided a clear basis for different stakeholders' buy-in in joining forces to support the project. There was a clear economic imperative to act, and consensus among stakeholders was achieved regarding the necessity of investing in the project to avert even greater damages in the future. Transparent estimation of the cost of inaction, highlighting the urgency of the issues and underscoring the project's

significance was effectively shared among stakeholders, serving to mobilise a wide range of participants and facilitating consensus building.

- Effective collaboration and co-ordination among a diverse array of private and public stakeholders, as outlined previously, proved instrumental in mobilising the expertise needed to enhance the project's effectiveness and in diversifying the funding and financing sources to implement the project (Table 3.4)

Table 3.4. Collaboration has been key in diversifying and accessing funding and financing for the implementation of the Fargo-Moorhead flood diversion project, United States

Funding sources	Financing sources
Federal appropriations USD 750 million, USD 437 million of which was allocated by the Infrastructure Investment and Jobs Act of January 2022 State grants: North Dakota: USD 850 million Minnesota: USD 86 million **Local revenues** USD 1 514 billion. Local residents approved multiple sales tax initiatives to fund the project, including payments during construction, debt payments and availability payments to the PPP developer for the annual operations and maintenance of the project	In addition to the funding, the project benefits from financing, such as loans, that will be repaid over time using the sales tax revenues: – The US Environmental Protection Agency issued a USD 569 million Water Infrastructure Finance and Innovation Act Loan. The low 2.08% interest rate on the loan will save area taxpayers about USD 438 million over the life of the loan. – The North Dakota Public Finance Agency issued about USD 55 million in State Revolving Fund Loans. – The US Department of Transportation's Private Activity Bonds (PABs) allocation allowed project sponsors to issue USD 273 million in green bonds for the transportation elements of the project.

Source: Adapted from the presentation by Morteza Farajian, Executive Director, Build America Bureau, US Department of Transport at the 1st preparatory meeting for the Compendium of Good Practices on Quality Infrastructure - Thematic Focus: Increasing Infrastructure Resilience to Natural Disasters that took place on 18-19 April 2023.

- Time and cost savings achieved through a public-private partnership (PPP) have been significant. This groundbreaking flood management project, the first of its kind in North America, is expected to save approximately USD 330 million in construction costs and expedite project completion by a remarkable 10 years, reducing the timeline from 16 years to just 6 years. These substantial savings in both time and cost can be attributed to several key factors:
  - The Red River Valley Alliance (RRVA), the PPP consortium responsible for delivery of the diversion channel and transportation infrastructure elements have contributed innovative technical solutions that align with the requirements set forth by the Metro Flood Diversion Authority (MFDA).
  - The MFDA has secured a fixed-price bid from the RRVA, effectively transferring the risks associated with delays and cost escalations to the private sector.
  - Private equity investors, holding debt in the project, are incentivised to ensure timely and efficient project delivery in order to receive payment, thereby aligning their interests with the successful completion of the project.

- **Cost reduction and increased effectiveness through public-private partnerships.** In particular, PPPs entail the following benefits for this project:
  - MFDA retains ownership and control over operating standards and other requirements.
  - RRVA, as the private sector partner, delivers innovative technical solutions following MFDA standards and requirements.

- Engineers and contractors work collaboratively to lower construction costs and deploy new technology.
- MFDA receives a fix-price bid and RRVA assumes the risks of delay, cost escalation and other costs related to uncertainty.
- The private entity holds the debt responsible for repayment on the private activity bonds and it is incentivised to deliver the project in order to get repaid for its investment.

Conclusions

The seven concrete infrastructure projects discussed in this chapter exemplify different ways to address infrastructure resilience by implementing specific prevention, reaction and rebuilding efforts.

The seven case studies present elements of prevention efforts and showcase the importance of preventive measures. Three of the case studies – the building of a bulk power station in a flood prone area in Accra, Ghana, the life-cycle approach in the Metro Rapid Transport (MRT) project in Jakarta, Indonesia and the use of data and the update of standards to increase road network resilience in Mozambique – present good practices in reaction efforts, showing that effective reaction efforts in the aftermath of extreme weather events and/or natural disasters result also in augmented prevention capacities. Two case studies – the restoration of a degraded ecosystem for preventing flooding and preserving social and economic stability and development in Colombia and the use of digital technologies and strategic preventive maintenance in Japan – present good practices in rebuilding efforts in a forward-looking and comprehensive way. Two case studies exemplify the importance of preventive measures for road network stability in India and the United States, showing how data, technology and collaboration ensure effective actions.

Chapter 2 of this Compendium summarises the lessons learned from these case studies into seven actionable good practices and clarifies enabling conditions in developing countries. The seven good practices for building infrastructure resilience to natural disasters are:

- Adopting a life cycle approach
- Ensuring interests' alignment through effective collaboration
- Conducting risk assessment
- Monitoring and measuring impacts
- Investing in capacity building and knowledge management
- Carrying out strategic preventive maintenance
- Deploying cutting-edge technology and fostering new design and innovation

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Compendium of Good Practices on Quality Infrastructure 2024

BUILDING RESILIENCE TO NATURAL DISASTERS

In an era defined by the urgent climate crisis, unpredictable weather patterns and increasingly frequent natural disasters, ensuring infrastructure resilience to such events is paramount. This report discusses ways of enhancing government capacities to prevent, react and rebuild, thereby minimising the impact of natural disasters on infrastructure assets and operations. It identifies data, collaboration and technologies as drivers of resilience, and highlights financial resources, technical skills and regulatory frameworks as key enablers. The report presents seven actionable principles to ensure infrastructure resilience, drawing from global good practices and in-depth analyses of infrastructure projects in Colombia, Ghana, India, Indonesia, Japan, Mozambique and the United States.

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